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THESIS

EXPERIMENTAL ANALYSIS OF INTEGRATION OF TACTICAL UNMANNED AERIAL VEHICLES AND NAVAL SPECIAL WARFARE OPERATIONS FORCES

by

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December 2002

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An experimental investigation was conducted to examine the use of small, expendable, endurance UAVs to enhance the combat effectiveness of Naval Special Warfare Forces (NSW). The experiment involved UAVs, NSW forces, and a red team in a downed-pilot rescue mission. Models were developed to determine optimum flight patterns for all UAVs. Models were also developed and utilized to determine experimental variables and measures of effectiveness. Simulation of the exercise was conducted to determine adequacy of the experiment plan.

It was found that UAVs significantly enhanced force protection, provided direct improvement in C2, significantly enhanced situational awareness, and provided the ability to track blue forces. It was found that video feed to blue force foot patrols may not be as valuable as having the C2 element dedicated to viewing the feed provide real-time COMS relay to the patrol. The exercises demonstrated that NSW forces do not need to launch and fly UAVs in order to utilize their capabilities; rather UAVs can be located and launched at the Forward Operating Base. The data obtained imply that small, expendable, endurance UAVs may do more than enhance capabilities for current missions, they may enable NSW Forces to conduct missions previously considered too high-risk.

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requirements for the degree of

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ABSTRACT

An experimental investigation was conducted to examine the use of small, expendable, endurance UAVs to enhance the combat effectiveness of Naval Special Warfare Forces (NSW). The experiment involved UAVs, NSW forces, and a red team in a downed-pilot rescue mission. Models were developed to determine optimum flight patterns for all UAVs. Models were also developed and utilized to determine experimental variables and measures of effectiveness. Simulation of the exercise was conducted to determine adequacy of the experiment plan.

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EXECUTIVE SUMMARY

This thesis consists of two separate, yet mutually dependent parts. One part is concerned with the organizational network of participants and development of a limited objective experiment that can test emerging technologies in an operational but analytical environment, and be repeated by follow-on students. The other part is concerned with the analysis of the actual integration of a small UAV with NSW forces during a specific NSW mission. The mission chosen in this case was a downed pilot scenario. The main objective of this second part was to show how a small, inexpensive, UAV could impact NSW combat effectiveness.

While the experiment did not come to full fruition, much data was collected, and analysis of that data yielded the following observations:

A well-planned operational experiment can be used as a tool for assessment of emerging UAV-technologies, but that assessment is limited to only those technologies specifically incorporated into the test. This means it is important to field as capable a vehicle as possible at the time of the experiment. Useful feedback, however, can be gathered to aid in the development of future technologies and to provide a critically evaluated determination as to how that technology may best be used to increase NSW combat effectiveness.

The loose network of participants utilized in this thesis effort did provide useful input into NAVSOF CONOPS

and TTPs, and the short-term future sustainability of the network looks promising. The link to operational commands will continue to be the most difficult to maintain as their primary concern is correctly placed on mission accomplishment, not research.

Finally, and most importantly, the research demonstrated that the use of a small, inexpensive UAV carrying, in this case, a low-light camera and simulated communications relay capability, launched by rear echelon personnel, flown by onboard autonomous avionics to prescribed and changeable waypoints, and emitting live video feeds to both the SEAL platoon in the field as well as the C2 element in the rear, proved to have a positive impact on the combat effectiveness of NSW forces.

The technology supporting small tactical UAVs is still developing. Optimal duration, speed, and payload capabilities do not currently exist in one aircraft. However, these capabilities are being rapidly developed and if money and interest were focused in a specific direction articulated by NSW, then perhaps this capability could be developed that much more rapidly. This direction provided by NSW should be based on a proven need, a need that will improve NSW combat effectiveness. Many engineers that were interviewed during the process of this thesis indicated the likely capability to rapidly produce the type of vehicle described above if a clear direction were given that included all necessary minimum requirements. Unfortunately, their many customers have greatly varied minimum requirements.

I. INTRODUCTION

A. PURPOSE

It is the purpose of this thesis to provide NSW forces, as well as other special operations forces, with quantitative Measures of Effectiveness (MOEs) and supporting data that can help guide development and operational employment of small UAVs to increase NSW combat effectiveness during a variety of NSW missions. It was planned that the data derived from this limited objective experiment (LOE) would produce a baseline of information which can be used to evaluate the use of small UAVs with regards to improved combat effectiveness through increased situational awareness, improved command and control (C2), and increased and more accurate intelligence. Achievement of these improvements would also improve target identification and forces protection.

As new technologies emerge, they can be tested and evaluated in a similar manner to that used in this initial limited objective experiment (LOE). The results can then be compared and contrasted to the baseline set of data to provide the NSW community, and SOF in general, with the information they need to continually evaluate UAV programs with regards to improving combat effectiveness as well as provide UAV developers with user feedback before and during product development so they can meet the specific needs of NSW and SOF.

Additionally, the network team created at the Naval Postgraduate School (NPS) during the first LOE can continue to provide the framework for future enhancement

of UAV/NSW integration as new technologies emerge and future NSW students perform new LOEs.

B. BACKGROUND

There is much research and information in existence that documents the general world of UAVs. A broad military use of UAVs has emerged over time with an evolving increase in UAV capabilities (UAV Roadmap 2025, 2001). The usefulness of UAVs is evident by their successful use in the War on Terror in Afghanistan, or as seen by the recent Predator missile attack in Yemen on an al-Qaeda terrorist, Ali Aqed Sinan al-Harthi, also known as Abu Ali, (USA Today, 05NOV02). However, these high profile missions also demonstrate a limitation. Predator, Global Hawk, and other UAVs like them are limited in number and expensive, and therefore are considered strategic assets. In fact, according to the Joint Special Operations Air Component Commander (JSOACC) during operation Enduring Freedom in Afghanistan, COL J. Tyner (USAF), it was easier for special operations forces to get support from B52s to drop bombs than it was for those same forces to get UAV support to “see what was over the next hill” (Tyner, 2002). A study of how SOF should best use UAVs determined:

> Control of SOF UAVs should go to those best able to utilize them with the general goal to push them as far down in the chain of command as makes sense. In other words, commanders should seek to empower small units without unnecessarily burdening them. (James, p. xiv)

UAVs are often categorized by the level of war they support. Strategic UAVs are large (the size of single pilot single engine aircraft) very expensive, limited in

number, and highly capable with advanced optics or sensors and even armament; for these reasons they are controlled by theater level commanders. The Predator, a strategic UAV, controlled from a submarine, verified intelligence and provided tactical information for a SEAL direct action training mission on a Silk Worm site in 1997 (Robinson, 1997, p. 18). In other words a strategic UAV provided tactical intelligence to a tactical unit or commander. Tactical UAVs are significantly less expensive, smaller than a manned aircraft, and somewhat more abundant. They carry less capable optics and sensors and have less endurance, such as the Army's Hunter or the Navy's Pioneer. Small or Mini UAVs, such as the Army's Sentry, Nighthawk or Pointer systems, fill a range between tactical UAVs and the smallest of all UAVs, the micro-UAVs. However, Micro-UAVs are normally considered very small, man-portable, fly for about an hour or less and carry simple sensor payloads (UAV Roadmap 2025, 2001). This thesis focuses on the small UAVs as bridging the gap between tactical UAVs, with regards to endurance and sensor payloads, and micro-UAVs that are dedicated to the single patrol element. It should be noted that technologies are rapidly changing which may both reduce costs while at the same time greatly improve payload capabilities and endurance for the smaller UAVs.

Tactical UAVs have already proven their usefulness to tactical commanders. "The Army's Pioneers flew 155 hours and 46 sorties providing a quick-fire link that allowed the targets they identified to be quickly engaged by other systems. Army Pioneers also helped tactical commanders to conduct situation development, targeting, route

reconnaissance, and BDA” (Pioneer UAV Incorporated, 2000). The small UAV examined in this thesis is much smaller than the Predator or even the Pioneer, but with advancements in design and technology, could have some of the same capabilities. While the strategic UAVs are no doubt of great value to those that have them at their disposal, it is highly unlikely that the majority of NSW forces conducting missions will be able to utilize them due to their limited number, high cost, and ultimately higher prioritized usage.

This thesis was narrow in scope. It was not intended to be an exhaustive research effort regarding UAV capabilities, or a document that identifies the exact UAV platform or its minimum requirements for NSW or SOF. Instead it attempted to fill in the perceived gap of information about small/mini UAVs and their usefulness to NSW. This information is then presented to help NSW leaders identify minimum UAV requirements and decide how best to improve NSW combat effectiveness to meet the operational objectives of the future set forth by the Secretary of Defense, articulated in the Navy’s Roadmap to Transformation, in the most efficient and effective manner possible. These operational objectives include:

> Protecting critical bases of operations (U.S. homeland, forces abroad, allies, and friends) and defeating CBRNE weapons and their means of delivery;
>
> Assuring information systems in the face of attack and conducting effective information operations;

> Projecting and sustaining U.S. forces in distant anti-access or area-denial environments and defeating anti-access and area denial threats;
>
> Denying enemies sanctuary by providing persistent surveillance, tracking, and rapid engagement with high-volume precision strike, through a combination of complementary air and ground capabilities, against critical mobile and fixed targets at various ranges and in all weather and terrains;
>
> Enhancing the capability and survivability of space systems and supporting infrastructure; and leveraging [sic] information technology and innovative concepts to develop an interoperable, joint C4ISR architecture and capability that includes a tailorable joint operational picture (Transformation Roadmap, 2002, p. 6).

While these are national defense objectives, NSW will be asked to conduct tactical missions to achieve them. Our senior defense leaders wish to “significantly improve naval contribution to joint battlespace [sic] awareness” and desire to “seamlessly link sensors to warfighters [sic]” and visualize that “the deployment of a family of Navy and Marine Corps UAVs, equipped with various sensors and networked via the Tactical Control System, will play a key role in extending the reach, coverage, and persistence of the naval ISR systems that provide information to the joint force” (Transformation Roadmap, 2002, p.10). It is the purpose of this thesis to show how small, inexpensive, UAVs may significantly increase the combat effectiveness of NSW forces in order to directly accomplish the identified U.S. national defense objectives above.

C. LOE IDENTIFICATION AND PLANNING

Based upon personal knowledge and experience with current SOF missions and operating procedures, it was

decided to focus this initial experiment on downed-pilot rescue; a mission for which the UAVs have potential for significantly improving concepts of operations. To develop interest and participation and to obtain recommendations for conducting the LOE a number of facilities and commands were visited; Commander Third Fleet, Naval Special Warfare Command, Naval Special Warfare Development Group, Naval Special Warfare Group 2, Office of Force Transformation, Office of Naval Research, Center for Naval Analysis, Naval Surface Warfare Center Carderock Division, the Lawrence Livermore National Laboratory (LLNL), and the Schafer Corp. in coordination with DARPA. The input received was utilized to initialize planning for the equipment and technologies to be employed as well as the operational forces to be utilized. In addition, initial efforts were made to establish relationships which would support future LOEs conducted at NPS. For example, the Lawrence Livermore National Laboratory has agreed to provide some of their latest sensors and COMMS for future UAV experiments. The customer for the LOE benefits from being able to experiment with the latest technologies, and LLNL has the opportunity to test and evaluate their latest technologies in an operational environment with well-defined objectives and measures of effectiveness.

II. ORGANIZATIONAL DEVELOPMENT

A. PARTICIPANTS AND FUNCTIONS

Primary researcher and experiment observer: LT Butner

Research advisors: Dr. Netzer, Dean of Research at NPS and Dr. DePoy, Director, Wayne E. Meyer Institute of Systems Engineering at NPS

Mathematical model developers: Class Project, Models of Conflict (SO4410) students at NPS; LT Butner, Maj Aiken, MAJ Barton

Flight model developers: Class Project, (SI3900), Systems Engineering and Integration students at NPS; MAJ Poh (SAF), MAJ Tan (SAF)

Simulation designer: Adaptation and application of recently completed thesis in Operations Research from NPS; CPT Alistair (AUA) (Alistair, 2002).

Experiment design assistance: MAJ Phillips (USA), TRADOC Analysis Center-Monterey

Airfield and UAV flight coordinator: Ray Jackson, Center for Interdisciplinary Remotely Piloted Air Systems (CIRPAS)

UAV concept leader: Vincent Castelli, Naval Surface Warfare Center Carderock Division (NSWCCD)

UAV producers: Advanced Ceramics Research (ACR), Tucson, AZ

Blue force participants: CW04(SEAL) Poladian, GMC(SEAL) Olson, QM1(SEAL) Cooper, IS1(SEAL) Duff, OS1(SEAL) Kolskie, BM1(SEAL) Beck, and MR2(SEAL) Huntimner

from Naval Coastal Systems Station, Panama City, FL and the Defense Language Institute (DLI) Monterey, CA.

Red force and downed pilot participants: Ten enlisted navy students from DLI.

Financial support: Center for Defense Technology and Education for the Military Services (CDTEMS) at NPS.

B. GUIDELINES AND TEMPLATE FOR EXPERIMENTS

1. Guidelines

One of the intents of this thesis effort was to develop general guidelines and a template for a series of LOEs to be conducted using unmanned vehicles. It was desired that the template provide the requirements and timing for experiment design, modeling and simulation support, data collection and analysis, and financial support. Some suggested guidelines are:

(1) Capitalize on research efforts in other departments or institutes that could enhance the effort. Laboratories such as the Naval Research Laboratory (NRL) and the Lawrence Livermore National Laboratory (LLNL) may provide useful innovations that can be incorporated into future experiments.

(2) Analytical research methods and modeling should be leveraged to identify Measures of Effectiveness (MOEs).

(3) Simulation can verify suitability of experiment design and help maximize efficiency.

(4) Whenever possible, multiple iterations should be run in the experiment instead of planning for one iteration, plan for an initial iteration, analyze the effectiveness of the iteration along with initial results, and then plan for a final improved iteration.

(5) One should not test untried operational concepts and untried technological equipment at the same time. Verify that the equipment being used in the experiment has met operational objectives prior to experiment usage. Time is limited at NPS and there is little room for unanticipated delays in fielding equipment.

(6) Establish a military sponsoring command if troops or military equipment are required for the experiment. Active duty units are very busy, and research is not the highest of their priorities. Locating NSW personnel that had the time to participate in an experiment was the most difficult aspect of coordinating this experiment; coordinating the UAV flights was the second most difficult aspect.

(7) The experiment needs to be kept small and with a minimum number of participants so that it can be effectively and efficiently completed in the time allotted for thesis work. The U.S. Navy’s Third Fleet is designated the Sea Based Battle Lab and is where innovative ideas are to be explored to improve war fighter effectiveness. NPS and the Commander Third Fleet (C3F) have established a close working relationship. The Fleet Force Command (FFC) has recently been assigned responsibility for coordinating and conducting Fleet experiments in the Seal Trial process, and the three NPS Institutes are establishing close ties with this command. However, most of these experiments are large and may limit the freedom and flexibility normally allowed the student at NPS. The Office of Force Transformation may also

provide assistance, ideas, funding, and other helpful contacts.

(8) Finally, ensure MOEs are developed early and that those MOEs drive the experiment design and analysis. The Dean of Research at NPS and the Wayne E. Meyer Institute of Systems Engineering are excellent places to present the research idea and tap into the ongoing research at NPS and elsewhere in that field. These are also excellent places to locate a potential thesis advisor with expertise in the field of interest.

2. Template

A general template follows with a brief description of how the template was utilized in the initial LOE.

(1) Determine/establish the war fighter requirement. This was based upon SECDEF and CNO transformation guidelines (DON, 2002), personal discussions with various commands (see II.A), and personal experience with NSW/SOF operations)

(2) Understand the current capabilities and shortfalls for meeting the requirements, both in technologies and concepts of operation. These were based upon personal knowledge and discussions with others in the NSW/SOF community. UAV and payload technologies for the desired expendable UAV characteristics were discussed with the NSWCCD, SWARM Program manager, and the UAV literature reviewed, for example: DOD’s UAV Roadmap 2025 (2001).

(3) Identify the technologies to be utilized, their maturity and availability, and the level of difficulty for their utilization. Ensure new operational concepts are not to be introduced using unproven technological

capabilities. These were based upon the SWARM Program Plan for time-lines and actual capability demonstrations before the experiment was to be conducted.

(4) Identify the personnel requirements for conducting the experiment. These were based on standard operating procedures (SOPs), tactics techniques and procedures (TTPs), and logistics involved in execution.

(5) Identify and secure adequate financial resources before proceeding with more detailed planning. Funding was arranged through the NPS Center for Defense Technologies and Education for the Military Services (CDTEMS).

(6) Lay out the initial experiment design, including the timing for personnel and equipment (described below).

(7) Ensure availability for personnel, equipment, and facilities for the planned dates of the experiment. This was achieved through multiple early meetings and requests. When shortfalls were identified, they could be immediately addressed. Forces utilized were obtained from multiple sources. The red force and downed pilots came from the Defense Language Institute Monterey, CA and the blue force SEALs came from Naval Coastal Systems Station, Panama City, FL.

(8) Review the experiment design with operational commands, (FFC, Naval Special Warfare Command (NAVSPECWARCOM), Naval Special Warfare Development Group (NAVSPECWARDEVGRU)), and a broad cross section of faculty at NPS (systems engineering, Modeling and Simulation

(M&S), technology experts, etc.) (See Participants and Functions, II A.)

(9) Determine what M&S will be required to adequately plan and conduct the experiment. Identity a range of experimental variables, fixed parameters, etc., and provide a model which can be (partially or fully) validated with the experimental data to be obtained. (See VII. Modeling and Simulation.)

(10) Use M&S to refine the experiment design. (Discussed below.)

(11) Develop a data collection plan and how the data will be utilized to determine quantitative and qualitative measures of effectiveness (MOEs). This will include personnel and personnel skills requirements. (Discussed below.)

(12) Develop an orientation/initial training plan to be conducted for all personnel involved in the experiment. This will include pre-experiment, experiment, and post-experiment activities. (See III E. Training/Orientation)

(13)Conduct the experiment and collect the data. (Discussed below.)

(14) Analyze the data and develop the MOEs and lessons learned. (Discussed below.)

(15) Summarize findings and brief relevant commands. (Thesis.)

III. LIMITED OBJECTIVE EXPERIMENT DESIGN

A. SCENARIO DESIGN

While SEAL patrols normally consist of a minimum of eight personnel, depending on the mission, two were considered to be adequate for purposes of this experiment. The additional SEALs in a patrol provide extra fire power and mission essential skills, but the standard operating procedures (SOPs) for two SEALs on patrol are basically the same as for eight. The footprint, or signature of their presence is reduced, but this should have minimal effects on the data to be analyzed. Additionally, a limited number of red force and blue force personnel were available. The use of two blue force personnel per search element meant that the red force element, made up of four personnel, would be double the size of the blue force. A red force double the size of the blue force was used in all M&S.

The experiment was designed to consist of a total of ten Combat Search and Rescue (CSAR) missions conducted at Camp Roberts, CA. The participants consisted of seven NSW SEALs. These SEALs filled two search teams, each with two SEALs per team. The remaining SEALs were part of the Command and Control (C2) element, one C2 element with one SEAL and one C2 element with two SEALs. The eight red cell personnel (two teams of four), two downed pilots (one per operational area), and multiple observers and support personnel made up the remainder of the participants. A two by four kilometer op area was chosen to allow for the maximum amount of data points to be collected while still

being able to conduct the mission within a single cycle of darkness. Five of these op areas were then chosen for their varying terrain and to ensure that participants were not operating in familiar territory. Personnel locations were to be changed in each op area to prevent any bias from a previous night’s mission. Each op area was to host two separate teams conducting the same mission on different nights. However, one team would be assisted by two tactical UAVs and one team would not. The op areas were to be used in a random order and the NSW search teams would not know what op area they would be inserted into until the night of the operation, nor would they know if they were to be assisted by UAVs until that night. This was to ensure teams could not help one another plan for that night’s mission. The scenario within one particular op area was exactly the same for each team except for the UAVs. All participants in a given op area were inserted in the exact same location as the other group that had utilized that op area the night before. The insertion locations of the participants relative to each other varied with each op area.

Nightly missions were to continue for a total of five nights, until both teams conducted all the same scenarios one time. This, however, was not accomplished, and only two separate nights of missions were conducted. The reason for this change will be described in more detail below. Each mission scenario varied only by location of crash sight, pilot, red cell, NSW team insertion point, and the geographical and terrain differences among the op areas. Distances between forces were nearly identical. This would allow for direct comparison of missions

conducted in the same op area and a general comparison of missions conducted in other op areas. The initial general scheme of force locations can be seen in Figure 1. During early experiment design and before a sight survey had been conducted, force locations were plotted in representative op areas and arrows were used to indicate the direction of travel to safety for the pilot.

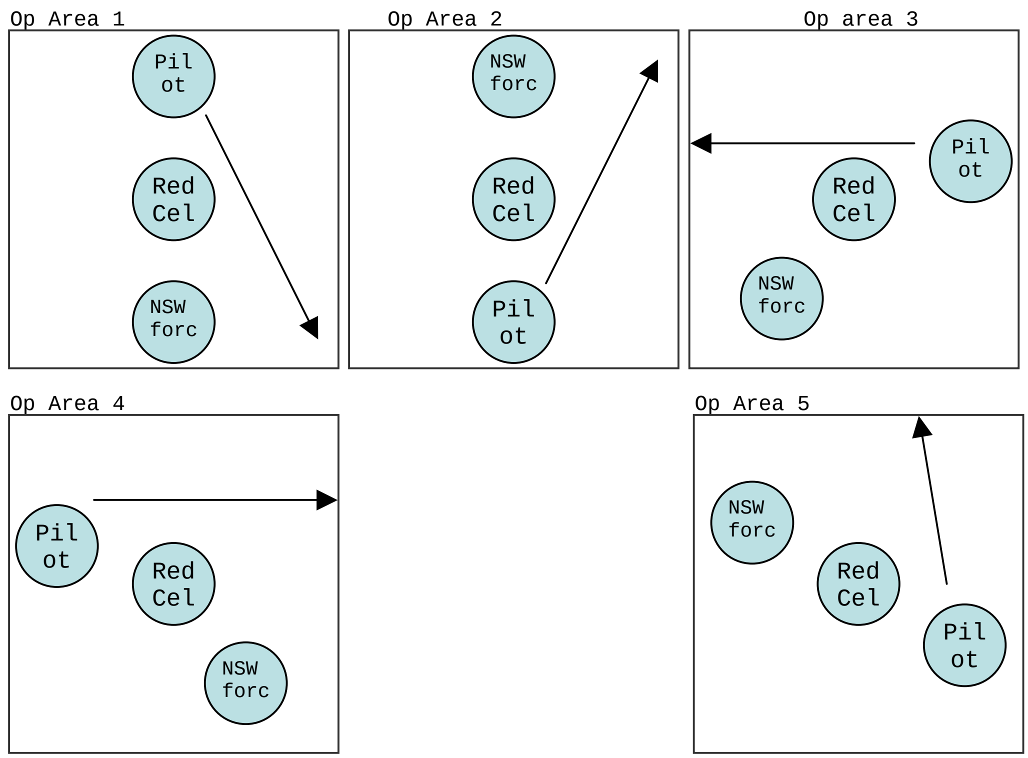

Figure 1. Initial Force Orientation

B. FORCE LOCATION

Two NSW teams, consisting of a two-SEAL patrol element and a C2 element, were to conduct two separate CSAR missions in two successive nights. Each night’s mission was to be conducted in a different four by two kilometer area (Fig. 2).

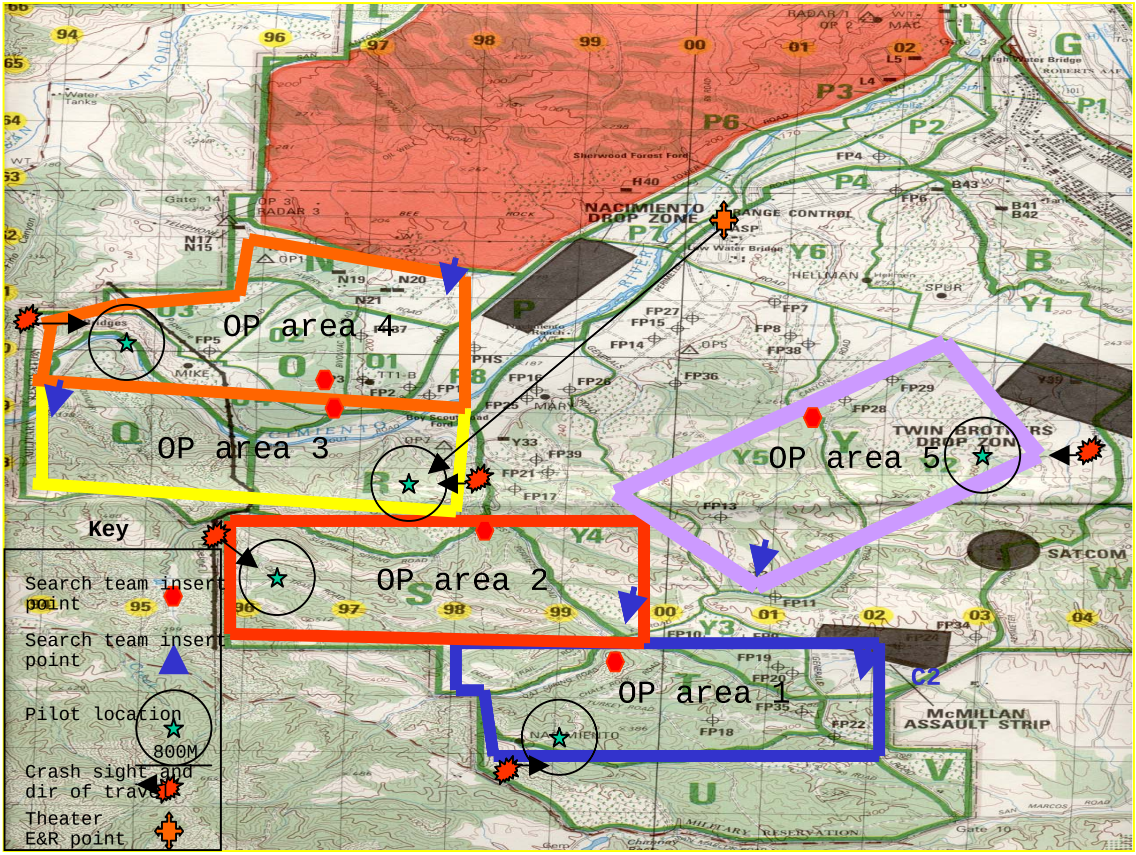

Figure 2. Force Location Overlay

In the figure above, and as indicated in the key, red force insertion points are represented by red Hexagons. The blue force insertion points are represented by blue arrows. The pilot’s location is represented by the green star within a black circle. This circle represents an 800M diameter area in which the pilot should be located with reference to his last known location. During the mission, the pilot could communicate with the blue search element when they came within range of his survival radio (simulated PRC 112). The pilot could then relay his position to the search element using a pre-established point, or an evade and recovery point (E&R), by giving his range and bearing from that E&R point. The NSW forces (C2

and search elements) were provided with intelligence usually available to a SOF team assigned a CSAR mission in an area controlled by the enemy; crash sight coordinates, last known position of pilot, positive radio communication/authentication, and most likely direction of travel(Joint Pub 3-50.2, p. II-6). Therefore the C2 element and the blue search element knew the crash site location, represented by the red explosion symbol, and the direction of the pilot's travel, represented by the black arrow. The blue forces also knew that the pilot intended to remain within 800M of his last known location for the first 4 hours after the mission began. If contact was not made within 4 hours, all blue forces were aware that the pilot would begin to move in the direction towards friendly territory, which was the same direction of initial movement. The C2 element, located at McMillan Assault Strip and represented by the blue C2 in Figure 2, remained at the assault strip for all missions and was collocated with the UAV pilot in the ground control station seen behind the UAV and launcher in Figure 3.

Figure 3. Ground Control Station

The red cell consisted of a four-man patrol of infantry personnel with little training, utilized to simulate a poorly trained conscript force. They patrolled a one by two kilometer area that contained the downed pilot's most likely position based on indicators suggested after initial simulation runs.

The downed pilot simulated evasion through a safe corridor by moving on a given bearing (after 4 hours) or by holding up near his last relayed position (800M diameter). This position was the position given to the search element as the pilot's last known point. As the search element came within line of sight (LOS) communications range, they would attempt to establish

communications with the pilot at which time he would update his position by giving a bearing and distance from a known point (the E&R point). All participants remained within the designated two by four kilometer area.

One of the NSW forces was to have been provided the additional asset of one or two small tactical UAVs. This force was to conduct its mission in the same manner as the non-UAV force except for the deviations that are driven by the use of the UAVs. The mission areas were to be exactly the same, as well as the locations of the red cell and downed pilot insertion points. The insertion point was also the same for both NSW forces, but the infiltration routes could differ based on information provided by UAVs. If two UAVs were available then one would be designated the pilot UAV and the other designated the patrol UAV. The pilot UAV would fly a flight pattern determined by a classical search theory for non-moving targets near a known point, taking into account the field of view of the video camera, the UAV altitude, and the UAV turning radius (Figure 4). The pattern in Figure 4 assumes that the UAV is at an altitude of 400ft. The field of view at this altitude is 90m so the horizontal paths across the search area are separated by 90m. The UAV starts at the bottom of the circle, moves right to left, makes the 180 degree turn determined by its turning radius, and then returns along a second path from left to right which is parallel to the first but offset by 90m. This would continue until the pilot is located, and the situational awareness (SA) pattern is initiated.

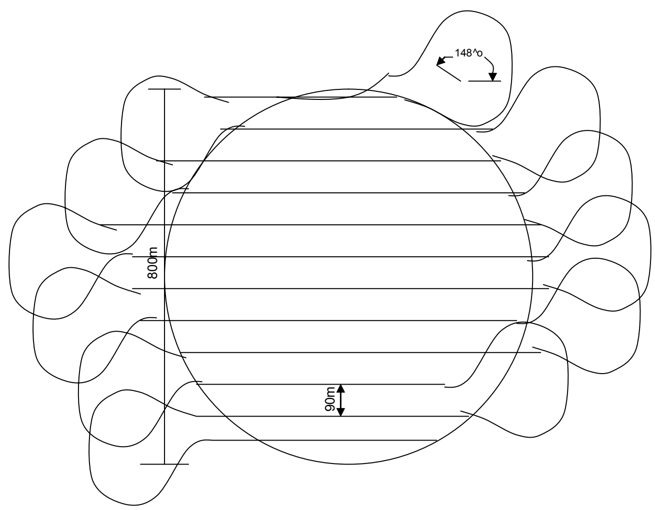

Figure 4. Downed Pilot Search Pattern

Once the downed pilot was located, the pilot UAV would then fly a situational awareness (SA) route to provide the C2 element with a one-kilometer radius SA zone about the downed pilot (Figure 5). This flight pattern would be repeated until the end of the mission and experiment.

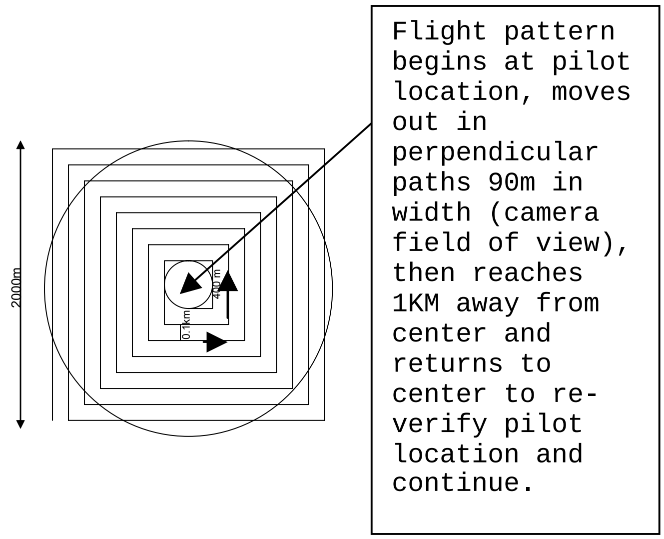

Figure 5. Pilot SA Zone

The patrol UAV would fly a flight pattern designed to maximize situational awareness of the patrol and the C2 element for a one-kilometer diameter perimeter about the patrol during their infiltration (Figure 6). This was again based upon the camera field of view, UAV altitude, and UAV speed.

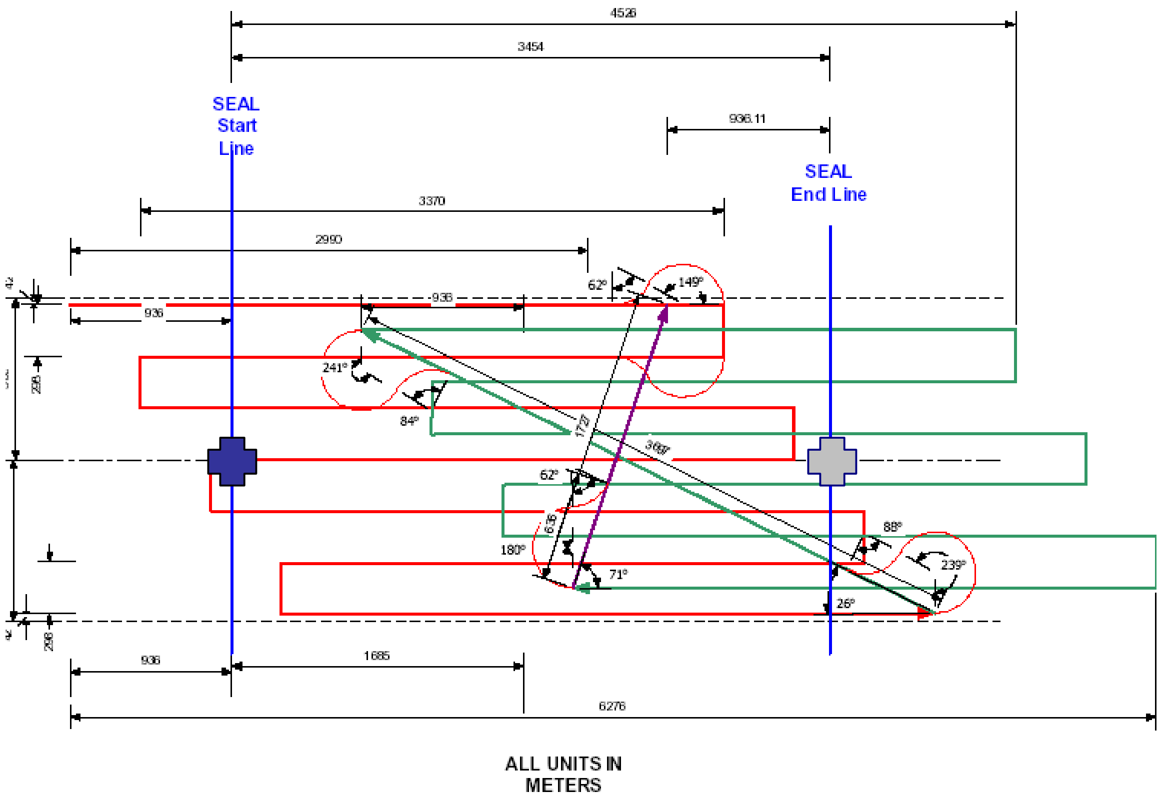

Figure 6. Patrol Flight Pattern

The blue cross in Figure 6 represents the SEAL search element as they begin to patrol moving in a straight line from left to right. The patrol UAV starts in the upper left-hand corner and follows the red flight path from left to right. Once the UAV reaches the end of the first red line the turn is initiated, indicated by the same dog-bone shapes seen in the pilot SA pattern. These turn angles are again dictated by the turning radius and speed of the UAV and are designed to return the UAV to the next parallel flight path, offset by 90m, as quickly as possible. The UAV then travels along the second red line from right to left. Once the end is reached the same dog-bone turn is made however, the remaining turns are deleted for clarity. Notice here that the UAV did not travel as

far down this second red line. This is because the blue force has moved from their initial starting point. Once all the red paths have been traveled the UAV ends up in the bottom right-hand corner and makes a turn onto the green diagonal line to return to a new starting point. The UAV begins the same pattern now indicated by the green lines. Notice the green pattern begins approximately 1.5km past the red pattern in the direction of blue force travel. This movement of the UAV's start point also takes into account the movement of the blue force. At the end of the green pattern when the UAV turns onto the purple path, the blue force has moved to the point indicated by the grey cross. At this point the red flight pattern can begin again. The red pattern can also be initiated if there is a long pause in the movement of the blue forces. The C2 element has the capability to redirect any of the UAVs in mid-flight.

Experiment observers were to track actual movements conducted by all participants to verify actual C2 and ground force situational awareness. A number of different recording methods could also be employed to help track movements and gather data, such as UAV over-flight recording tactical UAV movement, voice recording, manual note taking, and GPS waypoint tracking.

The force location diagram (Figure 1) was overlaid onto a map of the operational areas to be used during the experiment (Figure 2). This was done to add focus and purpose to a sight survey. The op areas were then chosen, after the sight survey, for their varied vegetation and terrain features. All operational areas also had to

remain within the restricted airspace available for UAV flights. The final force locations and operational areas can be seen in Figure 2 as they were to be utilized during the LOE.

While most of the operational areas in Figure 2 were utilized, the UAVs were unable to fly outside of visual range from McMillan Assault Strip due to a lack of adequate liability insurance for autonomous flight (a lesson learned regarding detailed planning requirements). This, of course, negatively impacted the design of the experiment. In addition, severe weather resulted in cancellation of the last two nights of operation. To make accommodations for these unforeseen effects, only two non-UAV missions were run. In addition, limited line of sight flights were conducted to test equipment and the user interface, and secondary autonomous flights were scheduled (and conducted) for 04DEC02-06DEC02 in a new location (Tucson, AZ). While a direct correlation between the missions with the UAV and those without could no longer be made, enough data was gathered to make strong inferences of effects on the identified MOEs.

C. DATA COLLECTION METHODS

1. Experiment Instructions to Participants and Qualitative Questionnaires

The following experiment instructions and questionnaires were given to each group before and following each night’s mission. The instructions ensured that quantitative data could be collected properly, emphasizing GPS waypoints as a function of time during the experiments. The questionnaire portion was developed to obtain further insight into the four MOEs that could not

be obtained through quantitative data alone, as well as to obtain specific information about the technical application of some of the equipment by the participants. The cumulative responses are provided in the data section of this thesis.

Blue Force Without UAV; Experiment Requirements and Questionnaire

Requirements:

Blue search element must carry GPS at all times. Position must be marked as waypoint on GPS every 10 minutes (GPS has one button function for this operation). Blue search element must notate all red force sightings/engagements/contacts with time and GPS coordinate. This may be done after the fact if compromise is possible. All pilot contact must be noted with time and GPS coordinate. All communications with pilot must be noted with time and brief one or two word description. If pilot position is known or estimated to be known, this should be annotated with time and approximate location. If pilot position is thought to have changed, this should be noted with time and approximate new position. Observer may be utilized to maintain event log and GPS waypoints if available. Locating the pilot without compromise (counter detection by red force) is the blue force mission.

The following questions are to be answered upon return from each mission and after return of GPS to experiment personnel.

Questionnaire:

(1) Qualitative responses to situational awareness/target identification questions.

1. How did you estimate the pilot position?

2. Did you know your position with confidence in relation to the pilot?

3. Upon detection of enemy, if any, how confident were you that this was an enemy force? Why?.

4. Upon detection of pilot, if any, how confident were you that this was the pilot, from what distance did you make this determination?

5. What actions did you take at this time, why?

6. If enemy contact was made, what actions did you take, why?

(2) Qualitative questions for force protection.

1. What actions did you take, if any, when provided enemy position?

2. How confident were you in the info passed to you, if any, by the C2 element?

Blue C2 Element Without UAV, Experiment Requirements and Questionnaire

Requirements:

Blue C2 element must track blue search force, red force (if possible), and pilot. Positions of all three forces must be marked as coordinates on a map every 10 minutes. If no change of position is noted, then this must be annotated in log every 10 minutes. Blue C2 element will act as on-scene commander for blue search element, conduct limited tactical operation center (TOC) functions, receive radio broadcast updates, and provide intelligence updates to forces in the field at the

discretion of the TOC commander. Senior commander to C2 element (commander not on scene) will require updates of noteworthy activity hourly. This will include major event times and locations (infiltration, link up, mission complete, enemy activity). C2 element will maintain radio and video watch during field operations. C2 element will maintain operations log with short entries every 10 minutes (force locations/time/major events). Extra support personnel/observers, if available, may be utilized for making log entries and updating maps. Locating the pilot without compromise is the blue force mission.

The following questions are to be answered by C2 element upon return of blue search element from each mission.

Questionnaire:

(1) Qualitative responses to situational awareness

1. Did you know force positions with confidence (level 1-10) in relation to each other?

2. How confident were you in the info passed to you by the blue force?

3. How did you determine your force’s position, what techniques did you use?

4. How did you determine pilot position?

5. How did you determine enemy position?

(2) Qualitative questions for force protection

1. Did you know the enemy position in relation to your force’s position with confidence (level 1 (low)- 10 (high))?

Blue Force With UAV; Experiment Requirements and Questionnaire

Requirements:

Blue search element must carry GPS at all times. Position must be marked as waypoint on GPS every 10 minutes (GPS has one button function for this operation). Blue search element must notate all red force sightings/engagements/contacts with time and GPS coordinate. This may be done after the fact if compromise is possible. All pilot contact must be noted with time and GPS coordinate. All communications with pilot must be noted with time and brief one or two word description. If pilot position is known or estimated to be known, this should be annotated with time and approximate location. If pilot position is thought to have changed, this should be noted with time and approximate new position. Observer may be utilized to maintain event log and GPS waypoints if available. Locating the pilot without compromise (counter detection by red force) is the blue force mission.

The following questions are to be answered upon return from each mission and after return of GPS to experiment personnel.

Questionnaire:

(1) Qualitative responses to situational awareness

1. Did you see the pilot on the video screen?

2. If so did this help you link up?

3. What actions did you take upon seeing the pilot on screen?

4. Did you see yourself on the video screen?

5. Did you know your position with confidence in relation to the pilot? Was this due to the ability to see the pilot or via GPS only?

6. Did you see terrain features or any other objects on the video screen, describe briefly, did this help operations in any way?

7. How confident were you in the info passed to you, if any, by the C2 element?

(2) Qualitative questions for force protection

1. Did you see enemy personnel or any other personnel on video screen?

2. Did you know the enemy position with confidence in relation to your position?

3. Was this confidence due to the ability to see enemy personnel/or provided by C2?

4. What actions did you take, if any, when provided enemy position?

5. Did you hear or observe the UAV?

6. Did the UAV make you feel vulnerable or secure, or neither?

7. Did UAV provide you with a 1KM “observed zone” about your position?

8. How would you better employ the UAV to improve your mission?

(3) Qualitative questions for target identification

1. Upon detection of enemy, if any, how confident were you that this was an enemy force? Why?

2. Upon detection of pilot, if any, how confident were you that this was the pilot, from what distance did you make this determination?

3. What actions did you take at this time/why?

(4) Technique of employment and hardware quality

1. How often did you view the video screen?

2. How did you maintain light discipline with screen/why?

3. How did you carry the screen?

4. How did you carry all other equipment?

5. Did any UAV related equipment hamper any normal field operations/how?

6. Was there a delay in response to your requests for aircraft movement/how much/how did this effect your operations?

7. Would direct control of aircraft benefit your operations/how/why?

Blue C2 Element With UAV; Experiment Requirements and Questionnaire

Requirements:

Blue C2 element must track blue search force, red force (if possible), and pilot. Positions of all three forces must be marked as coordinates on a map every 10 minutes. If no change of position is noted, then this must be annotated in log every 10 minutes. Blue C2

element will act as on scene commander for blue search element, conduct limited TOC functions, receive radio broadcast updates, and provide intelligence updates to forces in the field at the discretion of the TOC commander. Senior commander to C2 element (commander not on scene) will require updates of noteworthy activity hourly. This will include major event times and locations (infiltration, link up, mission complete, enemy activity). C2 element will maintain radio and video watch during field operations. C2 element will maintain operations log with short entries every 10 minutes (force locations/time/major events). Extra support personnel/observers, if available, may be utilized for making log entries and updating maps. Locating the pilot without compromise is the blue force mission.

Questionnaire:

The following questions are to be answered by C2 element upon return of blue search element from each mission.

(1) Qualitative responses to situational awareness

1. Did you see the pilot on the video screen?

2. If so, did this help you in your mission/how?

3. What actions did you take upon seeing the pilot on screen?

4. Did you see the blue search force on the video screen?

5. Did you know force positions with confidence in relation to each other? Was this due to the ability to see the pilot or via voice comms only?

6. Did you see terrain features or any other objects on the video screen, describe briefly, did this help operations in any way/how?

7. How confident were you in the info passed to you, if any, by the blue force?

(2) Qualitative questions for force protection

1. Did you see enemy personnel or any other personnel on video screen?

2. Did you know the enemy position with confidence in relation to your forces position?

3. Was this confidence, if any, due to the ability to see enemy personnel/or provided by the UAV in any way?

4. What actions did you take, if any, when provided enemy position?

5. Did the UAV provide you with a 1KM "observed zone" about the position of your search element?

6. Were you confident there were no enemy personnel in this zone, explain?

7. How would you better employ the UAV to improve your mission?

(3) Qualitative questions for target identification

1. How confident were you that you could identify different forces via video?

2. Did known UAV location help identify forces?

3. How could forces be identified better, if at all?

(4) Technique of employment and hardware quality

1. How often did you view the video screen?

2. How long could one person view the video without need of a break?

3. Did any UAV related equipment hamper any normal C2 operations/how?

4. Did any UAV related equipment enhance normal C2 operations/how?

5. Would direct control of the aircraft benefit your operations/how/why?

6. How did you communicate with UAV pilot and were there any delays in your requests?

Red Force; Experiment Requirements and Questionnaire

Requirements:

Red force must carry GPS at all times. Position must be marked as waypoint on GPS every 10 minutes (GPS has one button function for this operation). Red force must notate all blue force, UAV, pilot sightings/engagements/contacts with time and GPS coordinate. This may be done after the fact if engaged in a contact. Red force may engage any targets thought to be hostile. Capturing blue pilot is the red force mission.

Questionnaire:

The following questions are to be answered upon return from each mission and after return of GPS to experiment personnel.

(1) Qualitative questions for force protection

1. Did you see blue force personnel or any other personnel?

2. If so, what gave away their position or how did you locate them?

3. Did you hear or see the UAV?

4. If so what actions did you take, if any?

5. Did this help you locate the pilot or any other personnel?

<u>Downed Pilot; Experiment Requirements and Questionnaire</u>

Requirements:

Downed pilot must carry GPS at all times. Position must be marked as waypoint on GPS every 10 minutes (GPS has one button function for this operation). Pilot must notate all red cell sightings/engagements/contacts with time and GPS coordinate. This may be done after the fact if compromise is possible. All blue force contact must be noted with time and GPS coordinate. All communications with blue force or C2 must be noted with time and brief one or two word description. If blue force position is known or estimated to be known, this should be annotated with time and approximate location. If blue force position is thought to have changed, this should be noted with time and approximate new position. <u>Pilot mission is to be located and recovered by blue force without being compromised/captured by red force.</u>

Questionnaire:

The following questions are to be answered upon return from each mission and after return of GPS to experiment personnel.

(1) Qualitative responses to situational awareness

1. Were you told of your position in relationship to any other forces?

2. If so, did this help you link up with those forces?

3. What actions did you take upon being given this info, if any?

4. Did you have confidence in the location of yourself or others/why?

5. How confident were you in the info passed to you, if any, by the C2 element or blue force?

(2) Qualitative questions for force protection

1. Did you know the enemy position with confidence in relation to your position?

2. Was this confidence, if any, due to information provided by C2?

3. What actions did you take, if any, when provided enemy position?

4. Did you hear or observe the UAV?

5. Did the UAV make you feel vulnerable or secure, or neither?

6. Did the UAV help with your recovery or hamper, or neither?

7. How could the UAV have been better utilized to assist in your recovery?

D. VARIABLES

Dependent variables:

Amount of time to reach downed pilot

Likelihood of finding/detecting the pilot

Likelihood of detecting the red force

Likelihood of the search element being detected

Situational awareness

Independent variables:

Terrain

Force size, training, quality

Information

Distance

Signature

Speed (basically constant rate of movement for small troops)

E. MEASURES OF EFFECTIVENESS

The following general MOEs were the enabling objectives chosen for their impact on Combat effectiveness:

- Situational awareness
- Command and Control
- Target identification
- Force protection

The following specific MOEs were the measurable quantities that could lead to a judgment about the more general MOEs and combat effectiveness as a whole.

- Distance between blue forces and pilot
- Distance between red forces and all blue forces
- Number of blue force detections of red forces
- Number of red force detections of blue forces
- Time to link up between pilot and blue force
- Number of successful mission (link up without compromise)
- Command and Control (C2) red force location estimation
- C2 blue force location estimation
- C2 downed pilot location estimation
- Qualitative responses to usability of UAV equipment in the field

F. TRAINING/ORIENTATION

Two days were set aside to train all forces on the operational equipment and procedures as well as the data collection equipment and procedures. Each day consisted of six hours of instruction or hands-on practical training.

The operational equipment consisted of the following:

- UAVs, which the forces did not have to operate themselves, but were given a basic introduction

- Video receiver equipment, which was basic in operation and only needed to be prepped for field use or TOC use

- Tactical field radios, which the SEALs brought with them and already knew how to use.

This training and introduction took one to two hours and required about one hour of prep time for the forces. If NSW forces themselves are not required to directly operate the UAVs, their ability to incorporate them into NSW missions will require minimal amounts of training in the future.

The operational procedures training began with the overall exercise brief, a separate forces scenario brief, and a planning session for the forces, at which time questions could be answered about specific operational questions.

The second day consisted of six hours of introduction and training with the data collection procedures and equipment. The overall data collection goals were identified during the initial brief and the primacy of data collection over mission accomplishment was emphasized.

The data collection equipment consisted of the following:

- Data questionnaires (see III B)
- Infrared (IR) strobes; small firefly type, mounted to a 9-volt battery
- IR chemlights; IR chemical light sticks, simply “break and shake”

- Tape recorders; mini cassette type used to note events instead of paper
- GPS receivers; Garmen Vistas with local topo maps loaded

All data questionnaires were reviewed, and questions were answered. IR strobes, IR chemlights, tape recorders, and batteries were all disseminated, and proper function was ensured. A one-hour GPS receiver class was given that included specific necessary functions required during the LOE, followed by two hours of practical training with operating manuals available. All personnel were competent with the use of all data collection equipment and procedures by the end of the training period.

No deficiencies were noted in operational procedures or data collection due to lack of understanding or improper use of any equipment. The primacy of the collection of data, as opposed to mission accomplishment, allowed forces to concentrate on this aspect. The result of their efforts was a steady stream of uncorrupted data that was easy for the observer to gather and record.

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IV. UAV PLATFORM AND PAYLOAD DESCRIPTION

The original desired UAV characteristics were low-cost/expendable, organic, stealth, long endurance (>4 hours for experiment, >12 hrs for future use), night vision, precision location, no required SOF control (autonomous or C2 personnel control, but optional SOF control), and launch with no recovery. When the experiment was initially planned, the SWARM UAV being developed by NSWCCD was selected because it met all of the desired characteristics and because the development program plan would be capable of providing tested vehicles at the scheduled time for the LOE. This turned out not to be the case. Neither the endurance, level of night vision, nor the image resolution at flight speed met development objectives on time. This resulted in having to change the experiment plan and was a "lesson learned"; do not plan experiments for which all equipment/ technologies have not been demonstrated.

A. SWARM UAV GOAL CAPABILITIES

1. Program Goal; Platform Characteristics

Name:	Smart Warfighting Array of Reconfigurable Modules (SWARM) (Figure 7, front row)
Developers:	Naval Surface Warfare Center, Carderock Division (NSWCCD) and Advanced Ceramics Research
Dimensions:	4′ length x 3.5′ wingspan

Launch weight:	20 lbs.
Propulsion:	(fuel, engine, generator, mechanicals) 11.5 lbs.
Weight:	(Airframe, avionics, and communications) 4.5 lbs.
Payload:	4 lbs.
Engine:	OS.40, compression ignition, burns JP-5/8 fuel
Airframe:	Molded plastic, five-piece snap-fit assembly, no tools required, stowed in 50” x 7” x 17” box, ready to assemble
Speed:	60 kts cruise speed
Duration:	24 hrs. duration (FY02)
Range:	1500 n.mi.
Ceiling:	8,000 ft.

2. Program Goal; Payload Characteristics

EO/IR camera

CHEM/BIO sensors

Auto target sensor

Synthetic Aperture Radar (SAR)

B. UAV CHARACTERISTICS AT TIME OF LOE (ALTERNATE)

1. Alternate UAV Platform Characteristics

Due to the restricted flight time capability of the SWARM and the status of payload integration, an alternate vehicle (Figure 7, back row) was used in most of the experiments.

Figure 7. Alternate UAV Back Row/SWARM UAV Front Row

Name:	Extra Easy
Producer:	Hangar 9
Weight:	15 lbs
Wingspan:	65 inches
Length:	50 inches
Fuel capacity:	2 liters
Duration:	45 minutes – two hours
Engine:	Modified OS Max.46 producing approximately 1 Hp
Max Bank angle:	limited to +-15 degrees

Turn Radius:	minimum turn radius under autopilot control is approximately 250 meters
Frequencies:	902.6-927.4 MHz
Tuning Step in MHz:	400kHz,
Occupied bandwidth:	per channel is 350kHz
Emission Bandwidth:	350kHz per channel
Transmit power Watts:	1.0 W
Transmitter:	MHX 910, Microhard Systems
Launch Method:	Traditional rolling take-off used for autonomous flights. However, test catapult launch was successful with SWARM (Figure 8)

Figure 8. SWARM Catapult Launch

2. Transmitter Characteristics

Ground-station to aircraft and aircraft to ground-station, Command and Control link, 10nm range (not fully tested)

Antenna nomenclature:	Whip
Antenna Type:	5/8 wave
Antenna Gain:	3.5 dbi
Antenna Polarization:	Vertical
Antenna feed point:	height 3 meters
Receiver Nomenclature:	MHX 910, Microhard Systems
Receiver Sensitivity:	105 dB

Receiver frequency band: 902-930 MHz

Receiver antenna Type: 1/4 wave whip

Receiver antenna Gain: 10 dbi

3. Avionics:

Built by Cloud Cap Technology (541)387-2030. Screen shots taken of avionics software during the LOE can be seen in Figures 9 and 10.

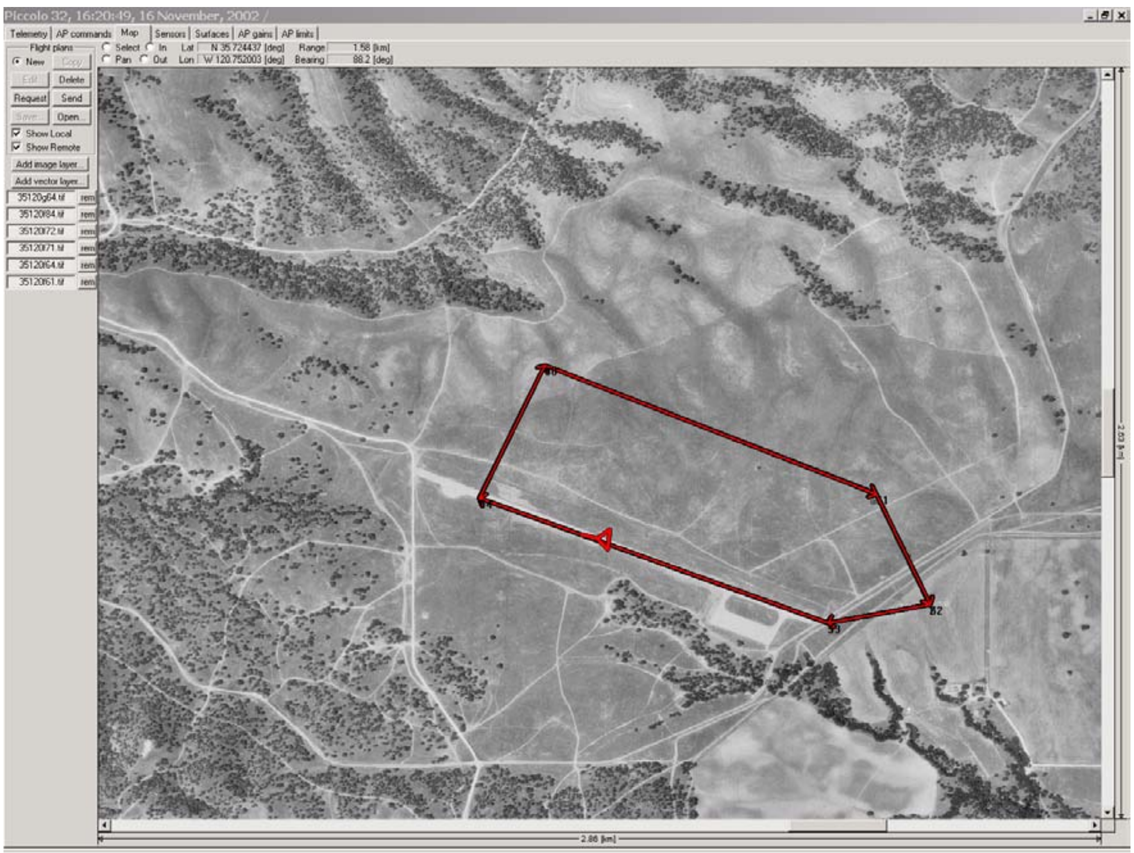

Figure 9. Test Route Over McMillan Assault Strip Camp Roberts

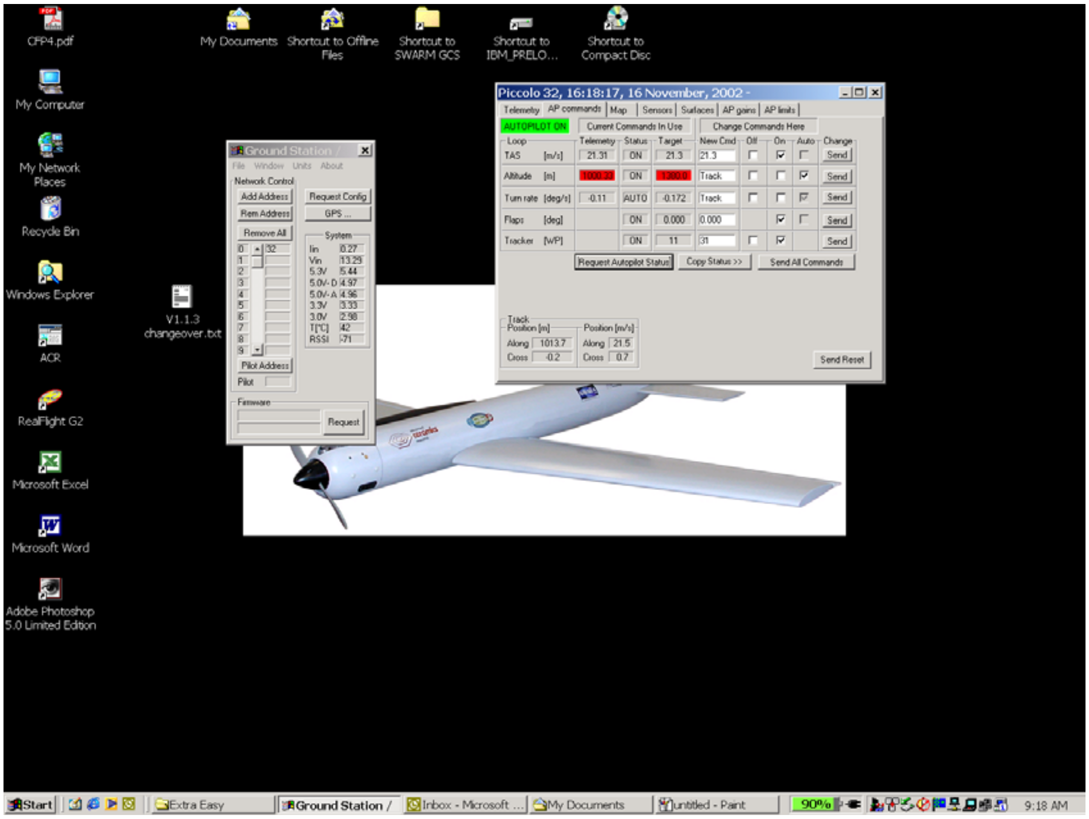

Figure 10. UAV Pilot Command Page

4. Payload Characteristics

<u>Camera:</u>

Type:	1/2" B&W 0.0003 Lux CCD
Wattage/Voltage:	2.2 W, 12 VDC, 180 mA
Resolution:	570 TV Lines
Manufacturer:	Watec (Model: LCL-802H)
Web site:	www.watec.com/bwboard.html
Weight:	70 g
Dimensions:	42 mm x 42 mm x 20 mm

Camera battery:

Capacity:	12 VDC, 2100 mA/H
Weight:	375 g
Lens:	12 mm (a spherical) Lens w/ Auto Iris
Wattage/Voltage:	0.4 W, 12 VDC, 35 mA
Look angle:	38.6 degrees diagonal
	31.2 degrees horizontal
	23.6 degrees vertical
Resolution:	Image Format 6.4 mm x 4.8 mm
Manufacturer:	COMPUTAR (Model: HG1208AFCS-HSP)
Weight:	146 g, (mounting platform w/ focus control adds 65 g)
Dimensions:	42 mm x 57 mm x 55 mm
Transmitter:	2.4 Ghz 1 Watt Wireless Video Transmitter

Batteries:

Capacity:	12 VDC, 2100 mA/H
Weight:	375 g

5. Other Equipment Characteristics

IR strobe:	Firefly, mounts to 9 volt battery, 2x3cm in size, mounted to personnel clothing with duct tape

IR chemlight:	Chemical light stick, IR spectrum, 4” long, 1/2” diameter

The use of the available camera described above required IR strobes to be placed on all forces. In other words, the camera could not detect humans on the ground in complete darkness, but it could detect these small strobes from an altitude of at least 4000ft AGL. The IR chemlights could not be detected above 800ft AGL and therefore were not used. The camera used did provide some daylight capability in black and white, but bright objects during the day could cause some “white out” effect. The camera was chosen for its low cost and size. There exist considerably more advanced cameras that have the same dimensions; however, price and time precluded their use in this initial LOE.

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V. DATA

A. DATA WITHOUT UAV

1. Quantitative Data Measuring Situational Awareness, Command and Control, Force Protection, and Target Identification

<u>04NOV02 Mission #1, alpha forces.</u>

- Number of blue force detections of red forces: One claimed but false; red force was 2500 meters away at time.

- Time to link up between pilot and blue force: 4h:2min.

- Positive link up: Yes.

- Number of counter detections by red force of blue force or pilot: None.

Figure 11 represents the actual locations of the forces (obtained from GPS waypoints every ten minutes) and their proximity to each other as they moved within the op area without the help of a UAV. These locations were to have been compared to a second group of forces utilizing a UAV. The closest proximity of red forces and blue forces or blue forces and the downed pilot could then be compared for missions with and without the use of UAVs. By itself this figure is a graphical representation of the courses the forces took during the scenario.

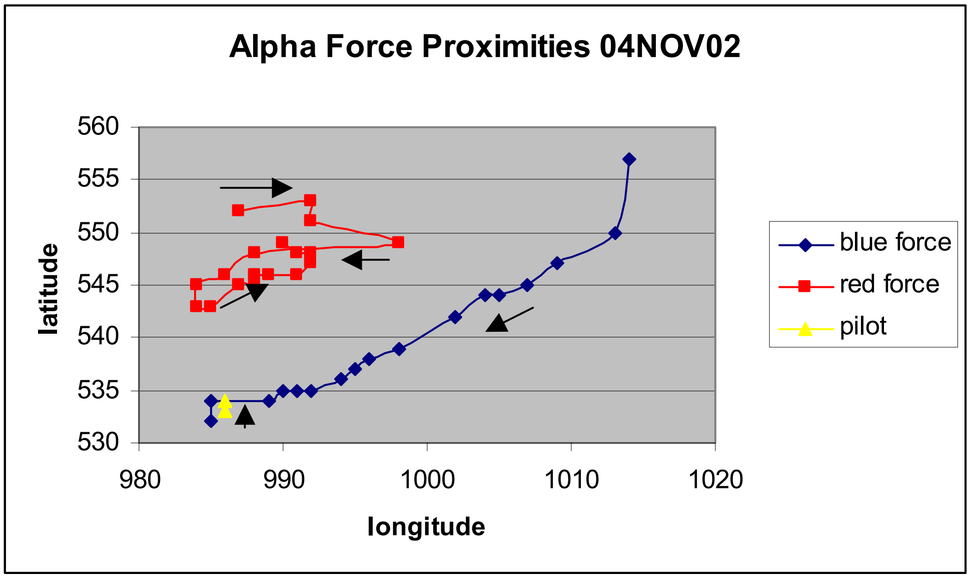

Figure 11.   Alpha Forces 04NOV02

Table 1 provides the situational awareness (SA) difference between a force's actual location and the C2 element's estimate. The two columns beneath "GPS track" contain the actual GPS location of the Blue force during mission number one in six digit grid coordinates. For example, Wave Point (WP) 1 UTM grid location is 014557, WP 3 UTM grid location is 009547. There are many data points for a single force as the force was on the move, and the points started at the beginning of the mission and ended when the pilot was located. The red force and downed pilot positions are given in separate tables. The next two columns under "C2 estimate" contain the C2 element's best guess as to where the blue force was. When the location matches exactly, this usually indicates a point when the blue force called back to the C2 element with a position update, which occurred only once an hour. The "difference" columns present the difference in hundreds of meters between the actual force location and the C2

element's estimate. The absolute value represents the SA difference between the actual force location and the C2's estimate. The SA differences are added at the bottom of the table and the average value is also given. The lower the number or difference the better. An SA difference of zero would indicate that the C2 element new exactly where the blue force was. The higher the number, the greater the error in estimation or the poorer the SA is.

Note: all data in the tables below represent hundreds of meters plus or minus 100 meters.

Mission # 1 (04NOV02), Alpha Forces								
WP	Blue force GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	14	557		18	547	-4	10	14
2	13	550		13	546	0	4	4
3	9	547		8	544	1	3	4
4	7	545		4	539	3	6	9
5	5	544		7	543	-2	1	3
6	4	544		5	540	-1	4	5
7	2	542		3	548	-1	-6	7
8	2	542		2	535	0	7	7
9	998	539		1	533	3	6	9
10	998	539		0	530	2	9	11
11	996	538		990	537	6	1	7
12	995	537		998	535	-3	2	5
13	994	536		986	533	8	3	11
14	992	535		987	532	5	3	8
15	991	535		987	532	4	3	7
16	990	535		987	532	3	3	6
17	989	534		993	533	-4	1	5
18	985	534		992	531	-7	3	10
19	985	534		981	539	4	-5	9
26	985	532		986	532	-1	0	1
Cumulative SA difference								**142**
Average SA difference								**7.1**

Table 1. Blue Force Alpha 04NOV02

Mission # 1 (04NOV02), Alpha Forces								
WP	Red force GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	990	549		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
2	990	549		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
3	991	548		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
4	992	548		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
5	992	547		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
6	991	546		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
7	989	546		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
8	988	546		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
9	988	546		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
10	988	545		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
11	987	545		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
12	985	543		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
13	984	543		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
14	984	545		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
15	986	546		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
16	988	548		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
17	998	549		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
18	992	551		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
19	992	553		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
26	987	552		986	528	1	24	25
Cumulative SA difference								**25**
Average SA difference								**25**

Table 2. Red Force Alpha 04NOV02

Mission # 1 (04NOV02), Alpha Forces								
WP	Pilot GPS track			C2 and Blue Force estimate of pilot location		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E		N		
1	986	534		987	532	-1	2	
2	986	534		987	532	-1	2	3
3	986	534		987	532	-1	2	3
4	986	534		987	532	-1	2	3
5	986	534		987	532	-1	2	3
6	986	534		987	532	-1	2	3
7	986	534		987	532	-1	2	3
8	986	534		987	532	-1	2	3
9	986	534		987	532	-1	2	3
10	986	534		987	532	-1	2	3
11	986	533		987	532	-1	1	3
12	986	533		987	532	-1	1	2
13	986	533		987	532	-1	1	2
14	986	533		987	532	-1	1	2
15	986	534		987	532	-1	2	2
16	986	534		987	532	-1	2	3
17	986	534		987	532	-1	2	3
18	986	534		987	532	-1	2	3
19	986	534		987	532	-1	2	3
34	986	534		986	532	0	2	3
Cumulative SA difference								**55**
Average SA difference								**2.8**

Table 3. Pilot Alpha 04NOV02

<u>04NOV02 Mission #1, bravo forces.</u>

- Number of blue force detections of red forces: None.
- Time to link up between pilot and blue force: 2h:30min
- Positive link up: Yes.

- Number of counter detections by red force of blue force or pilot: None.

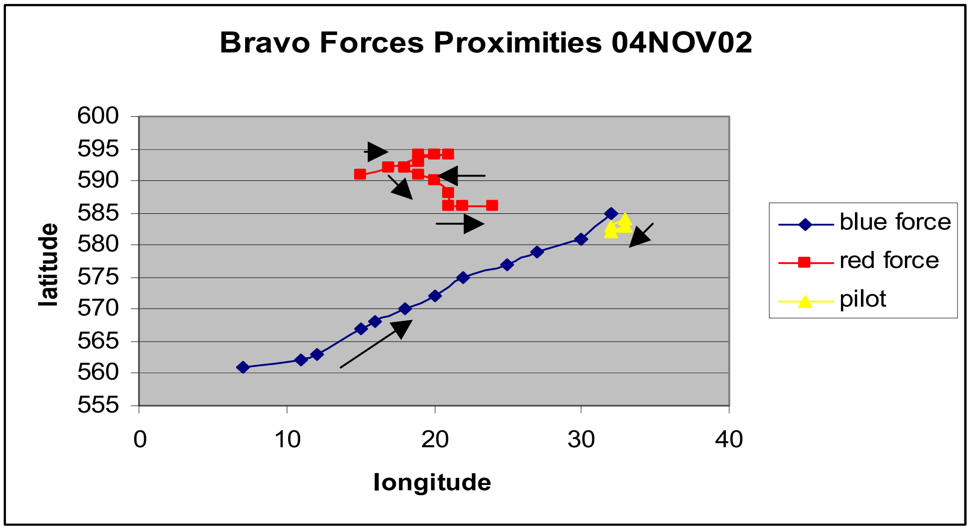

Figure 12. Bravo Forces 04NOV02

Mission # 1 (04NOV02), Bravo Forces								
WP	Blue Force GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	7	561		8	560	-1	1	2
2	11	562		13	561	-2	1	3
3	12	563		15	564	-3	-1	4
4	15	567		16	566	-1	1	2
5	16	568		18	570	-2	-2	4
6	18	570		22	573	-4	-3	7
7	20	572		24	574	-4	-2	6
8	22	575		23	573	-1	2	3
9	25	577		26	576	3	1	4
10	27	579		28	579	2	0	2
11	30	581		29	580	1	1	2
12	30	581		31	582	-1	-1	2
13	32	585		33	584	-1	1	2
14	32	585		33	584	-1	1	2
15	32	585		31	584	1	1	2
16	32	585		33	584			
Cumulative SA difference								**47**
Average SA difference								**3.1**

Table 4. Blue Force Bravo 04NOV02

Mission # 1 (04NOV02), Bravo Forces								
WP	Red Force GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	15	591		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
2	17	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
3	17	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
4	20	594		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
5	21	594		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
6	19	594		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
7	19	593		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
8	18	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
9	18	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
10	18	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
11	19	591		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
12	20	590		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
13	21	588		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
14	21	586		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
15	22	586		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
16	24	586		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
Cumulative SA difference				Unknown				#VALUE!
Average SA difference				Unknown				#VALUE!

Table 5. Red Force Bravo 04NOV02

Mission # 1, (04NOV02), Pilot								
WP	Pilot GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	33	584		32	585	1	-1	2
2	32	583		32	585	0	-2	2
3	32	582		32	585	0	-3	3
4	33	583		32	585	1	-2	3
5	33	583		32	585	1	-2	3
6	33	583		32	585	1	-2	3
7	33	583		32	585	1	-2	3
8	33	583		32	585	1	-2	3
9	33	583		32	585	1	-2	3
10	33	583		32	585	1	-2	3
11	33	583		32	585	1	-2	3
12	33	583		32	585	1	-2	3
13	33	583		32	585	1	-2	3
14	33	583		32	585	1	-2	3
15	33	583		32	585	1	-2	3
16	32	582		33	584	-1	-2	3
Cumulative SA difference								**34**
Average SA difference								**2.8**

Table 6. Pilot Bravo 04NOV02

05NOV02 Mission number two, alpha forces.

- Number of blue force detections of red forces: None.
- Time to link up between pilot and blue force: 2h:58min
- Positive link up: Yes.
- Number of counter detections by red force of blue force or pilot: None.

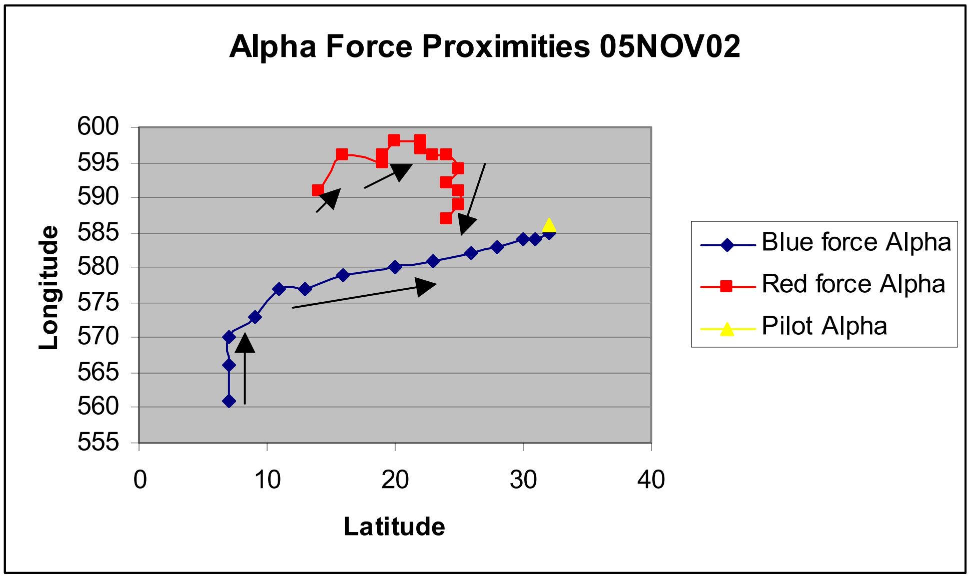

Figure 13. Alpha Forces 05NOV02

Mission # 2 (05NOV02), Alpha Forces								
WP	Blue Force GPS Track		C2 estimate			Difference E	Difference N	Absolute Value Situational Awareness Difference
	E	N		E	N			
1	7	561		8	560	-1	1	2
2	7	561		6	565	1	-4	5
3	7	566		7	570	0	-4	4
4	7	570		11	573	-4	-3	7
5	9	573		14	578	-5	-5	10
6	11	577		12	575	-1	2	3
7	13	577		19	576	-6	1	7
8	13	577		23	579	-10	-2	12
9	16	579		27	580	-11	-1	12
10	20	580		31	583	-11	-3	14
11	20	580		33	584	-13	-4	17
12	20	580		24	579	-4	1	5
13	23	581		27	580	-4	1	5
14	26	582		31	583	-5	-1	6
15	28	583		32	582	-4	1	5
16	30	584		33	584	-3	0	3
17	31	584		33	584	-2	0	2
18	32	585		33	584	-1	1	2
Cumulative SA difference								**121**
Average SA difference								**6.7**

Table 7. Blue Force Alpha 05NOV02

Mission # 2 (05NOV02), Alpha Forces								
WP	Red Force GPS track			C2 estimate		Difference E	Difference N	Absolute Value Situational Awareness Difference
	E	N		E	N			
1	14	591		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
2	16	596		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
3	19	595		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
4	19	596		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
5	19	596		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
6	20	598		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
7	20	598		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
8	22	598		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
9	22	598		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
10	22	597		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
11	23	596		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
12	24	596		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
13	25	594		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
14	24	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
15	24	592		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
16	25	591		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
17	25	589		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
18	24	587		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
Cumulative SA difference						Unknown	Unknown	#VALUE!
Average SA difference						Unknown	Unknown	#VALUE!

Table 8. Red Force Alpha 05NOV02

Mission # 2 (05NOV02), Alpha Forces								
WP	Pilot GPS track			C2 estimate		Difference E	Difference N	Absolute Value Situational Awareness Difference
	E	N		E	N			
1	32	586		33	584	-1	2	3
2	32	586		33	584	-1	2	3
3	32	586		33	584	-1	2	3
4	32	586		33	584	-1	2	3
5	32	586		33	584	-1	2	3
6	32	586		33	584	-1	2	3
7	32	586		33	584	-1	2	3
8	32	586		33	584	-1	2	3
9	32	586		33	584	-1	2	3
10	32	586		33	584	-1	2	3
11	32	586		33	584	-1	2	3
12	32	586		33	584	-1	2	3
13	32	586		33	584	-1	2	3
14	32	586		33	584	-1	2	3
15	32	586		33	584	-1	2	3
16	32	586		33	584	-1	2	3
17	32	586		33	584	-1	2	3
18	32	586		33	584	-1	2	3
Cumulative SA difference								**54**
Average SA difference								**3**

Table 9. Pilot Alpha 05NOV02

<u>05NOV02 Mission number two, bravo forces.</u>

- Number of blue force detections of red forces: None.
- Time to link up between pilot and blue force: 2h:40min
- Positive link up: Yes.
- Number of counter detections by red force of blue force or pilot: None.

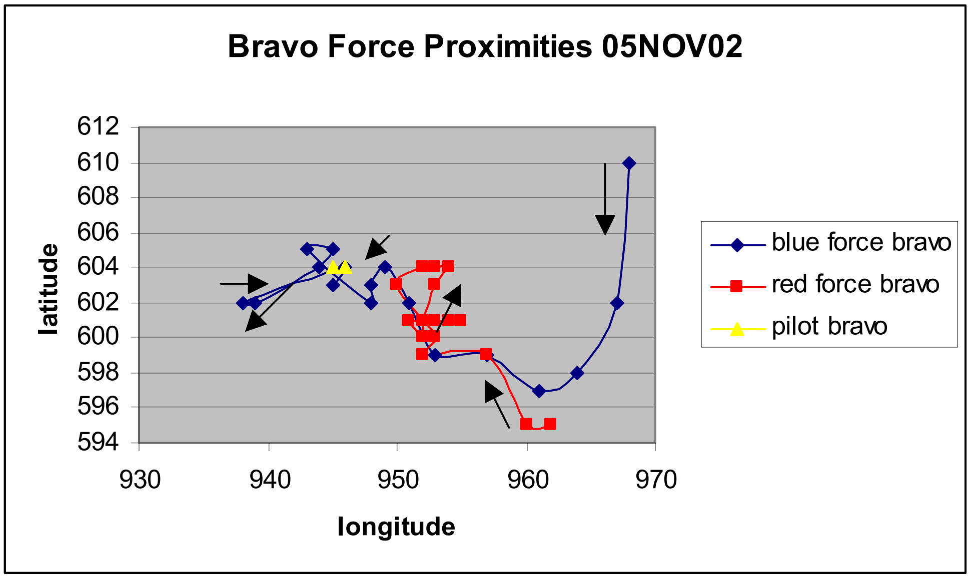

Figure 14. Bravo Forces 05NOV02

Mission # 2 (05NOV02), Bravo Forces							
WP	Blue Force GPS track		C2 estimate		Difference E	Difference N	Absolute Value Situational Awareness Difference
	E	N	E	N			
1	968	610	978	610	-10	0	10
2	967	602	974	607	-7	-5	12
3	964	598	971	607	-7	-9	16
4	961	597	969	604	-8	-7	15
5	957	599	966	601	-9	-2	11
6	953	599	962	600	-9	-1	10
7	951	602	952	600	-1	2	3
8	949	604	948	601	1	3	4
9	948	603	946	603	2	0	2
10	948	602	946	603	2	-1	3
11	943	605	946	603	-3	2	5
12	945	605	945	603	0	2	2
13	944	604	945	603	-1	1	2
14	939	602	945	603	-6	-1	7
15	938	602	945	603	-7	-1	8
16	946	604	945	603	1	1	2
17	945	603	945	603	0	0	0
Cumulative SA difference							**112**
Average SA difference							**6.6**

Table 10. Blue Force Bravo 05NOV02

Mission # 2 (05NOV02), Bravo Force								
WP	Red Force GPS track			C2 estimate		Difference E	Difference N	Absolute value Situational Awareness Difference
	E	N		E	N			
1	962	595		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
2	960	595		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
3	957	599		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
4	952	599		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
5	953	600		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
6	950	603		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
7	952	604		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
8	953	604		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
9	954	604		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
10	953	603		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
11	952	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
12	952	600		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
13	951	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
14	952	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
15	953	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
16	954	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
17	955	601		Unknown	Unknown	#VALUE!	#VALUE!	#VALUE!
Cumulative SA difference						Unknown	Unknown	#VALUE!
Average SA difference						Unknown	Unknown	#VALUE!

Table 11. Red Force Bravo 05NOV02

Mission # 2 (05NOV02), Bravo Force								
WP	Pilot GPS track			C2 estimate		Difference E	Difference N	Absolute Value Situational Awareness Difference
	E	N		E	N			
1	945	604		945	604	0	0	0
2	946	604		945	604	1	0	1
3	946	604		945	604	1	0	1
4	946	604		945	604	1	0	1
5	946	604		945	604	1	0	1
6	946	604		945	604	1	0	1
7	946	604		945	604	1	0	1
8	946	604		945	604	1	0	1
9	946	604		945	604	1	0	1
10	946	604		945	604	1	0	1
11	946	604		945	604	1	0	1
12	946	604		945	604	1	0	1
13	946	604		945	604	1	0	1
14	946	604		945	604	1	0	1
15	946	604		945	604	1	0	1
16	946	604		945	604	1	0	1
17	946	604		945	602	1	2	3
Cumulative SA difference								**18**
Average SA difference								**1.1**

Table 12. Pilot Bravo 05NOV02

2. Qualitative Data

Blue force:

All blue forces utilized the last known point of pilot’s position and UHF line of sight radio communications with pilot to approximate pilot’s position.

Blue forces were confident in the general position of pilot but had little confidence in exact position. Communications were necessary to verify position and there was still some lack of confidence especially in the more challenging terrain.

In establishing target identification, one blue force felt very confident on one mission that the pilot was authentic by establishing authenticity via radio communication with bona fides. However, blue forces did not feel confident on all remaining missions until pilot was very near or in custody and could answer more specific questions to authenticate. In one instance the blue force almost walked directly into pilot's position.

Blue forces felt confident in information passed to them by the C2 element.

Downed pilot:

Downed pilots never knew their positions in relation to any other forces. In one mission, a downed pilot confused the blue search element by relaying slightly incorrect information about his position. This created almost an hour delay in the pilot's recovery. In another mission, the red force walked within 25 meters of the pilot's position while the pilot lay motionless in a hide sight. The pilot was undetected by the red force.

Downed pilots had moderate confidence in their exact location (5 out of a 10 point scale).

Downed pilots were strongly confident in information passed to them from the blue force (10 out of 10).

Command and Control element:

The C2 element had moderate confidence (5 out of 10) in the relative positions of the blue force and the downed pilot. Last known positions, radio communications, briefed standard operating procedures, and estimated

movement direction and speed were used to attempt to accurately track forces.

The C2 element never knew the positions of any red force.

The C2 element was very confident (10 out of 10) in the information passed to them by the blue force. However, some of this information was discovered to be slightly inaccurate, but the C2 element had no way to verify the information.

<u>Red force:</u>

The red force never detected blue forces or downed pilots in any of the missions. Note for analysis; this would make it difficult to "improve" using UAVs except for confidence level in their own position. In future LOEs there should be more red team success without UAVs.

B. DATA WITH UAV

1. Quantitative Data

Due to the fact that the UAVs were unable to fly the profiles originally anticipated, the quantitative data that could have been directly compared to the data without UAVs was unobtainable. Instead, data collected from separate flights, without ground forces, and with IR strobes representing fixed force locations had to be interpreted. These outside-scenario flights were treated as a snap shot of the events that occurred during the original scenario that had moving troops on the ground. This allowed the data taken with the UAV to be compared to a single set of data taken from the experiment with ground forces but without UAVs. For this reason, the data

presented below is not in the same exact format as the data collected for the scenarios without the UAVs.

At the Arizona test site, a two by four kilometer box was used as the op area, and infrared strobes were placed in the box in three locations to represent the downed pilot, blue force, and red force, respectively. Four sorties of UAV flights that lasted just under one hour each were flown over the op area to locate the three separate forces (IR strobes). The C2 element (one Army SF MAJ) observed the video screen in the tactical operation center (TOC) next to the UAV pilot. When the C2 element observed a strobe, the UAV pilot was informed, and the UAV pilot provided a verbal location of the UAV in latitude and longitude (later converted to Universal Transverse Mercador (UTM) grid coordinates). This location was then plotted by the C2 element. Only one data point could be collected for each force (IR strobe). The true GPS locations in UTM $\pm$100m are given in Table 13 in a similar format to the many data points per moving force given in multiple tables for the non-UAV missions. The average situational awareness (SA) difference is a comparable figure to the average SA difference in all other SA tables. The lower the SA difference the better. Notice should be taken of the fact that the red force was never located in the scenarios without the UAV and that the red force position was plotted without any SA error at all $\pm$100m.

Table 13 provides SA difference for a single point only, but for all forces within the op area. The first row is the name of the force (IR strobe). The next two

rows are the actual locations of the strobes reduced to 6 digit UTM grid coordinates used most often by ground forces. This means the actual grid coordinate for the Blue Alpha force was 056537. The actual grid coordinate for the Pilot Alpha was 030536 located beneath the Blue Alpha coordinates in the second and third row. The grids were separated into two columns to allow for accurate comparisons of error when the C2 element estimated the force locations. The next two rows containing data are the C2 estimates of the force locations which is the same as the UAV pilot's report of the UAV location when the C2 element observed a strobe. The next two rows are the difference between the actual location of the forces (or strobes) and the C2's estimate of those locations. Because negative numbers can be a valid result, the absolute values are then accumulated in the final row. The absolute value is the true difference in locations of the forces because the coordinates represent locations and the absolute value represents differences in those locations in any direction. The absolute values, now identified as the difference in situational awareness (SA), are added together at the bottom of the table, and the average is also given. If the SA difference were to be zero, this would mean there was no difference between the actual location of the forces (strobes) and the C2's estimate of that location. This is the most desired SA difference. If the number is unknown, this would be the worst SA difference because the C2 element would have no idea of a forces actual location.

Mission (05DEC02) Alpha									
Force	GPS track			C2 estimate		Difference E	Difference N	Absolute value	
	actual location			2 estimates then average				Situational Awareness	
	E	N		E	N			difference	
estimate one				56	538				
estimate two				54	538				
BLUE ALPHA	56	537		55	538	1	-1	2	
Pilot A	30	536		29	536	1	0	1	
						0	0		
estimate one				36	542				
estimate two				34	540				
Red A	35	541		35	541	0	0	0	
Cumulative SA difference								**3**	
Average SA difference								**1**	

Table 13. Blue Force, Red Force, Pilot Location Data, 05DEC02

Sortie data:

Max altitude: 2614 feet AGL (most flights were conducted at this altitude.

Durations: Flights ranged from 36 to 66 minutes in duration. 66 minute duration approached maximum duration and is limited by fuel and battery life.

Fuel consumption: Average of 35 oz/hour

Max range from launch: Approximately 8km

2. Qualitative Data

Two flights were flown at Camp Roberts on 06NOV02 with troops on the ground conducting limited downed pilot

scenarios in a small 1km square area. The UAV was flown under manual control at approximately 400ft and 30knts, which provided a picture that moved too fast across the ground to determine force location relationships at night. Due to liability issues, the UAV was flown by remote control within visual range of a pilot on the ground instead of autonomously from a ground control station. This low altitude had to be maintained to allow the pilot to maintain visual contact with the UAV.

This limited scenario was conducted at night to test the ability of the UAV camera to see IR strobes during flight as well as test the video receivers and screens the search element carried in the field. Forces in the field found it impractical to view a video screen at night, near a target area (1km or closer). The video screens were very bright and ruined the night vision of the member of the search element that viewed it. The light emanating from the video screen was also difficult to mask. The search element covered the screens in red tinted plastic bags in an attempt at managing light discipline but were unsuccessful at solving the problem adequately during this time period. The 4”x6”x2”video screen was carried inside the shirt after carrying it in cargo pockets proved to be too cumbersome. The antenna, battery, and receiver fit well in a small Alice pack with plenty of room to spare. In this limited scenario, blue forces did not want direct control over the UAV if good communications could be maintained with C2 and directions could be rapidly given to the UAV pilot.

Having resolved liability issues, four sorties were flown on 05DEC02 in Tucson, AZ at Leroy Airport. The UAVs were able to fly autonomously at altitudes of about 2000ft. This allowed the C2 element much more time to view the IR strobes as they moved more slowly across the screen. However, the differences in each force's strobes, brightness, and periodicity were harder to detect at this altitude and at greater distances from one another, which made it harder to determine which force was which. A second op area was set up farther away from the UAV launch point but could not be used due to the limited range of the analog video which had a max range of about eight km and a working range of about three to four km. The autonomous flight control system worked perfectly during all four sorties and flew preprogrammed flights paths without error.

Flight paths developed for the original scenarios were not utilized due to the fact that the forces (strobes) would not be moving. A simple flight pattern consisting of back and forth, slightly overlapping paths was utilized to find all stationary forces (strobes).

A fifth sortie was flown on 06DEC02 to test an engine with better fuel economy. This UAV flew for one hour and twenty-five minutes and landed with some fuel still onboard.

It is also important to note that NSW forces were never required to operate the vehicles but merely receive their sensor data. This does not mean that contractors need to accompany the vehicles during possible future employment. On the contrary, the goal of the developers,

and the feedback of desired capabilities from NSW participants, is to design a vehicle that can be launched with minimal training. This merit would appear to prohibit the use of larger UAVs such as the Hunter. “A report by TRW on experiences in the Balkans notes that contractors provided 70 percent of the maintenance on the Hunter UAVS” (Robinson, 2002, p. 2). This maintenance requirement would seem to be an unacceptable situation for a force that is often required to deploy rapidly with a minimal logistics tail.

VI. DATA ANALYSIS

A. MEASURES OF EFFECTIVENESS

While all specific MOEs could not be evaluated due to the limitations placed on the experiment, enough data was gathered to demonstrate or infer a positive impact from the use of UAVs. A direct improvement to situational awareness for the C2 element can be seen in the empirical data below. Positive target identification will require more sophisticated equipment, but even the simple IR strobes used in this LOE could help improve target identification if used creatively. Force protection could be greatly enhanced if the low-light camera were replaced with a thermal imaging camera. The unique IR strobe placed on the red force during the LOE represented this capability and greatly enhanced force protection simply by knowing the location of any enemy personnel within the op area.

The “cumulative SA difference” seen above in tables 1 through 13 represents the total amount of error in hundreds of meters that the C2 element accumulated as they attempted to track the blue forces, the pilot, and the red forces. The number figure should not be viewed as important on its own but should be viewed as important when the average is used as a tool for comparison. The SA difference is like a golf score, the lower the better. The greater the SA difference the more error was involved in the C2 elements tracking of the forces. This figure can be compared for missions conducted in the same op areas with the same amount of distances involved.

The “Average SA difference” can be used to compare different op areas or different missions that perhaps have more datum points. Noted earlier the worst of all SA differences is the complete unknown location. This means the C2 element could not even estimate the red force location because they had absolutely no information to make any type of estimation. This is obviously the least amount of situational awareness or the greatest amount of SA difference between a forces actual location and the location that the C2 elements estimate they are in.

In Tables 1 through 13, the C2 element can be seen as being more accurate when tracking the pilot’s location. This is due to the fact that the pilots only moved a short distance from their last known point. Had the operations taken longer, over four hours, and the pilots began to move, the SA difference would surely increase.

The average SA difference for the flights conducted with the UAV was much lower than the average SA for all other forces without the UAV. This is the most significant finding as it is the most directly comparable data. The figures below are derived from tables 1-13 and show the minimal average error in SA for the C2 element with the UAV as compared to the somewhat larger average error in SA for the C2 element without the UAV.

<u>Non-UAV data:</u>

- Non-UAV Blue Alpha SA 04NOV 7.1
- Non-UAV Red Alpha SA 04NOV 25.0
- Non-UAV Pilot Alpha SA 04NOV 2.8

-	Non-UAV Blue Bravo SA 04NOV	3.1
-	Non-UAV Red Bravo SA 04NOV	Unknown!
-	Non-UAV Pilot Bravo SA 04NOV	2.8
-	Non-UAV Blue Alpha SA 05NOV	6.7
-	Non-UAV Red Alpha SA 05NOV	Unknown!
-	Non-UAV Pilot Alpha SA 05NOV	3.0
-	Non-UAV Blue Bravo SA 05NOV	6.6
-	Non-UAV Red Bravo SA 05NOV	Unknown!
-	Non-UAV Pilot Bravo SA 05NOV	1.1

UAV Data:

-	UAV Blue Alpha SA 05DEC:	2.0
-	UAV Red Alpha SA 05DEC:	1.0
-	UAV Pilot Alpha SA 05DEC	0.0

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VII. MODELING AND SIMULATION

A. DESCRIPTION OF MODELS

The multiple departments at NPS that participated in this thesis provided excellent models which helped design the LOE to maximize the amount of usable data to be retrieved. Models were used to develop two specific objectives; identification of the most efficient flight patterns and identification of the variables and the measures of effectiveness (MOEs). An adapted form of the derived optimum flight patterns were programmed into the UAV avionics/control system to provide autonomous operations.

1. Models for Optimum Flight Patterns

The flight patterns were developed by MAJ Poh and MAJ Tan of the Singapore Air Force, both international students at NPS, as an end-of-the-quarter project for their Systems Engineering and Integration course, in response to my request. The information provided below that details how the patterns were developed is taken directly from their project and is fully attributable to them.

The Measures of Effectiveness (MOEs) utilized for both the downed pilot flight pattern and patrol flight pattern were based on the requirement of having a one kilometer diameter of situational awareness. This one kilometer diameter is an estimate of the distance required for a SEAL patrol to react to the ability of an enemy force to detect a moving SEAL patrol (or pilot) without sensors in a variety of terrain (and have enough warning

to evade detection). MAJ Poh and MAJ Tan concluded that for the patrol flight pattern, they needed to maximize coverage area, minimize length of search pattern, and maximize the distance of look-ahead buffer as the patrol would most often be moving forward. These requirements conflicted with one another, and therefore an optimization scheme had to be developed. The optimal pattern developed can be seen in Figure 5, but this pattern only resulted in a coverage factor of .40. In other words, the maximum amount of area that could be covered, given the characteristics of the UAV (speed of 35knts, turning radius of 250m, and sensor field of view of 90m at 400ft altitude), the movement of the force, and the desired coverage area, was only 40 percent.

In order to increase the coverage factor the developers suggested to either fly two UAVs in the above pattern, which could double the coverage factor, or increase the altitude to 800ft, which would accomplish the same thing. Flying two UAVs was not practical due to a limited number of aircraft available at the present time and the difficulties that would arise in flying two unmanned aircraft in close proximity. After some field experimentation, it was discovered that the aircraft could fly at 800ft or higher and still acquire the infrared strobes utilized by both enemy and friendly forces. This meant that, theoretically, 100 percent of the desired area could be covered or a coverage factor of 1.0 could be achieved. As it turned out an altitude of 2000ft was used. This provided approximately a 500m field of view on the ground. This would provide 100 percent coverage in an area greater than that of the initially derived 1km

diameter. It also meant that a simpler flight pattern could be utilized.

The downed pilot search flight pattern developed was a simple design used to search about the last known point of the downed pilot's location. This pattern incorporated the assumption that the downed pilot would be no further than 400 meters from the last known position given, which is how the LOE scenario was designed. This pattern can be seen in Figure 3.

The third pattern developed was designed to be flown by the downed pilot search UAV after the pilot was located. The same one kilometer diameter area of coverage required by the search element was then desired for the downed pilot. This would prevent enemy forces from approaching the downed pilot undetected, as well aid the search team in locating the pilot as rapidly as possible while continuing to avoid the enemy. This flight pattern is presented in figure 4.

2. Mathematical Model for Experiment Variables and MOEs

Another model was developed by a research team that consisted of the author and two other Models of Conflict (SO4410) classmates; U.S. Army MAJ Mike Aitken and U.S. Air Force MAJ Phil Barton. This model was developed primarily to identify the experiment variables and MOEs. The model also helped determine the feasibility of the LOE by analyzing the force distributions within the search area and the probability of the forces detecting each other, which can be seen in figure 16 at the end of this section. The model was based on traditional mathematical modeling procedures (Giordano, Weir, and Fox, 1997, p.39).

The problem:

Produce a mathematical model that can represent the effect/value of a tactical UAV on a NSW CSAR mission.

Dependent variables:

- Amount of time to reach downed pilot
- Probability of finding/detecting the pilot
- Probability of detecting the red force
- Probability of the search element being detected
- Situational awareness

Independent variables:

- Terrain
- Force Size, training, quality
- Information
- Distance
- Signature
- Speed (basically constant rate of movement for small troops)
- UAV asset

Interrelationships among variables:

Speed is relatively the same for both groups (3km per hour) and will not change drastically near the objective area, therefore distance or area to be covered determines time (t=d/v = d/const).

Distance is a function of the area to be searched. The required search area, in turn, is inversely proportional to the amount of information or intelligence available. The blue search element should have more information about the downed pilot's location than the red force, therefore the area they are required to cover should be smaller and the time needed shorter.

Terrain will be the same for all involved and should not impact one group more than the other except in the most extreme conditions (pilot trying to hide in open flat desert); therefore it can be neglected except to determine the area to be searched.

Force, number of troops, training, morale, etc. were neglected as variables in this simplified analysis.

Signature affects detection probability.

Situational awareness is a function of C2 and sensors. In this model, "sensors" referred to the UAV. C2 effectiveness usually depends on the ability of the command element to know the information and pass it along to the search element. In this model C2 was considered perfect, in other words the command element knows all the sensor knows and relays this without difficulty to the search element so the search element has the same information and situational awareness. Therefore, situational awareness was only a function of the UAV asset and the force employing it.

Probability of detection of all forces is the key dependent variable to be modeled and in its simplest

form is a function of amount of time and situational awareness.

Model Solution:

GIVEN CAPABILITIES			
forces	SPEED km/hr	VISIBILITY WIDTH m	SEARCH AREA km^2/hr
UAV	60	90	5.4
Red	3	10	0.03
Blue	3	10	0.03

Table 14. Search Capabilities

- Patrol area coverage rate: (3km/hr)(.01km) = $.03km^2/hr$
- UAV area coverage rate: (60km/hr)(.09km)

  = 5.4 km^2/hr
- Red force coverage rate: (3km/hr)(.01km)

  = $.03km^2/hr$

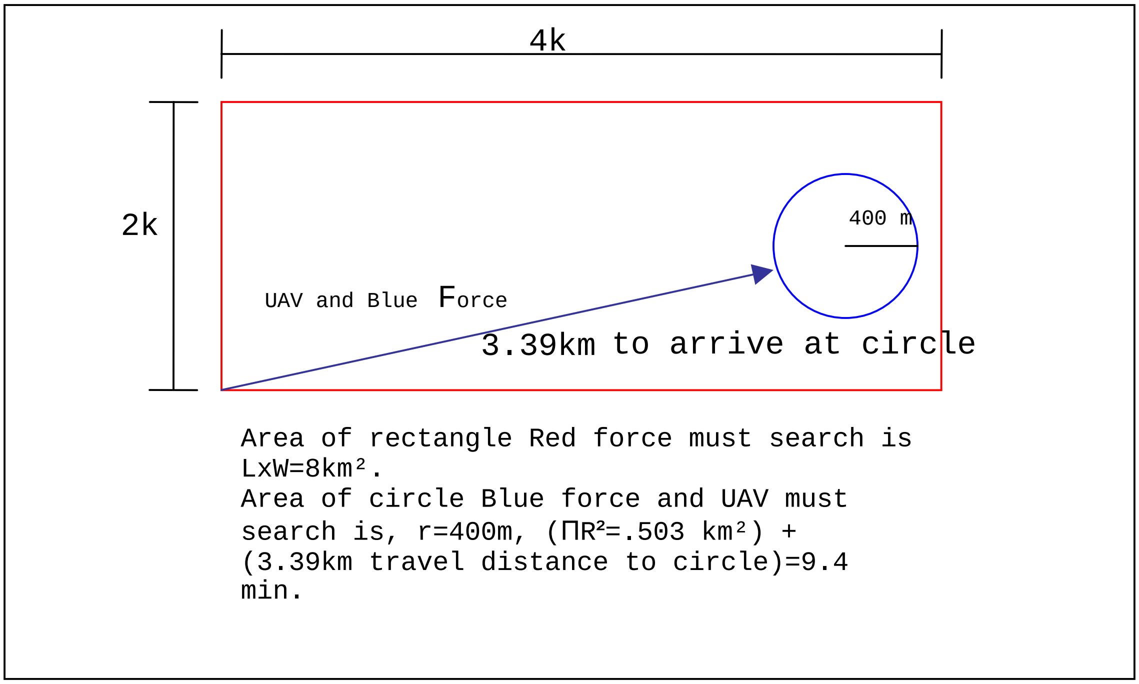

Figure 15. Search Area Calculations

- Select the search area based upon the amount of information or intelligence available, which is different for the Red and Blue forces (Figure 15).

- Determine the amount of time searches should take for each force

TIME REQUIRED TO SEARCH GIVEN AREA				
	AREA km^2	TRAVEL TIME hrs.min	SEARCH SPEED km^2/hr	TIME hrs.min
UAV	0.503	6 min	5.4	9 min
Red	8	0	0.03	277 hr
Blue	0.503	1 hr	0.03	17 hrs

Table 15. Time to Search Given Areas

Table 15 demonstrates how the estimated search times were derived. The UAV row, for example, divides the

area required to search (the circle), .503 km^2 by the search speed capability of 5.4km^2/hr, which equals .093hrs or approximately 6min. The travel time to the circle is also added, (3.39/60=.0565 or 3.4min), for a total of (6+3.4)= 9.4min.

Probability of detection is a function of the amount of the time used and the situational awareness of the forces during that time. This should be able to be seen (Figure 16) as a Normal distribution with the probability of detecting the pilot on the y-axis and area on the x-axis.

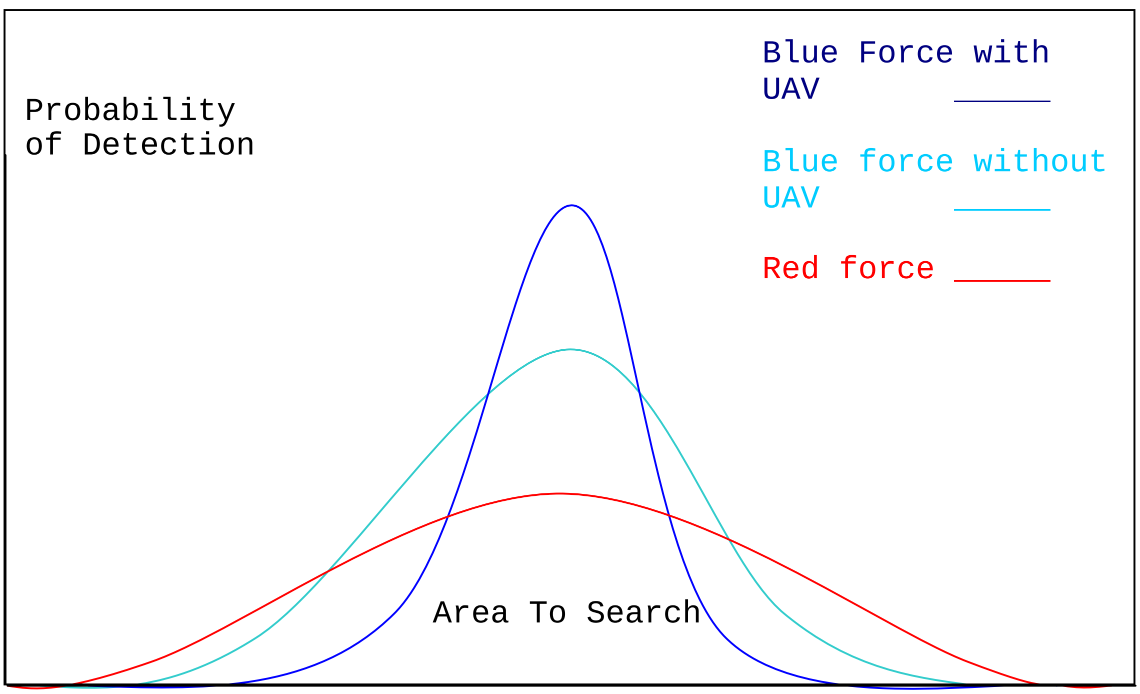

Figure 16. Search Area Distributions for Forces Searching for a Downed Pilot

Note: Blue Force with a UAV has the same SA as the UAV since perfect communication has been assumed. Also, an observation was made during the identification of the variables that unless there is going to be a force-on-force confrontation then the effect of the size of the force is marginalized. In fact, to accomplish missions in which no enemy is to be contacted by design then the smallest force possible to complete the mission is the force of choice in relationship to probability of detection for all parties.

The amount of time each force will take to search is directly proportional to the area each force is required to search. The time can be substituted for the area on the x-axis and plotted versus the probability of detection on the y-axis yielding a cumulative probability of detection, which can be seen in Figure 17.

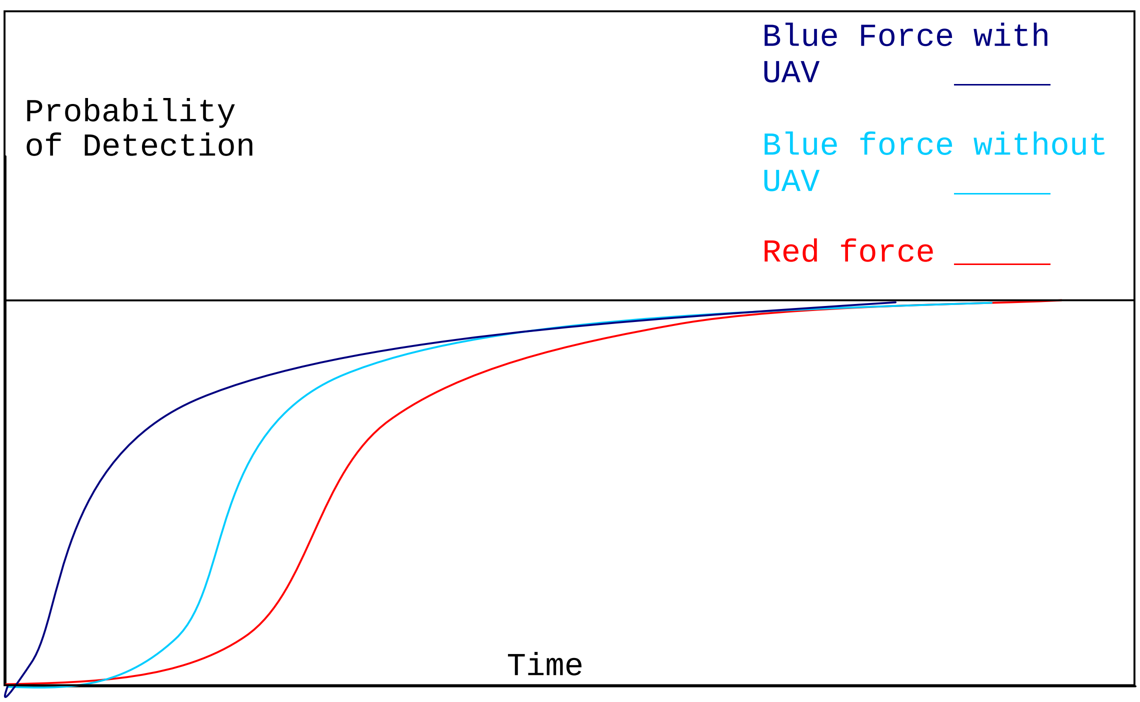

Figure 17. Cumulative Probability of Detection

The following distribution graph is another representation of the areas each force must search to find the pilot. This is done by displaying the pilot's possible location, from the perspective of the searching forces, given the intelligence provided each force and the op area distances. This model presents two main ideas: the first is that the red force is too disadvantaged to make this a reasonable experiment if a representation of the effect of the UAV is desired. The second is the addition of the UAV asset should reduce the time it takes the blue force to locate the pilot due to the reduced area needed to search (represented in green in figure 18).

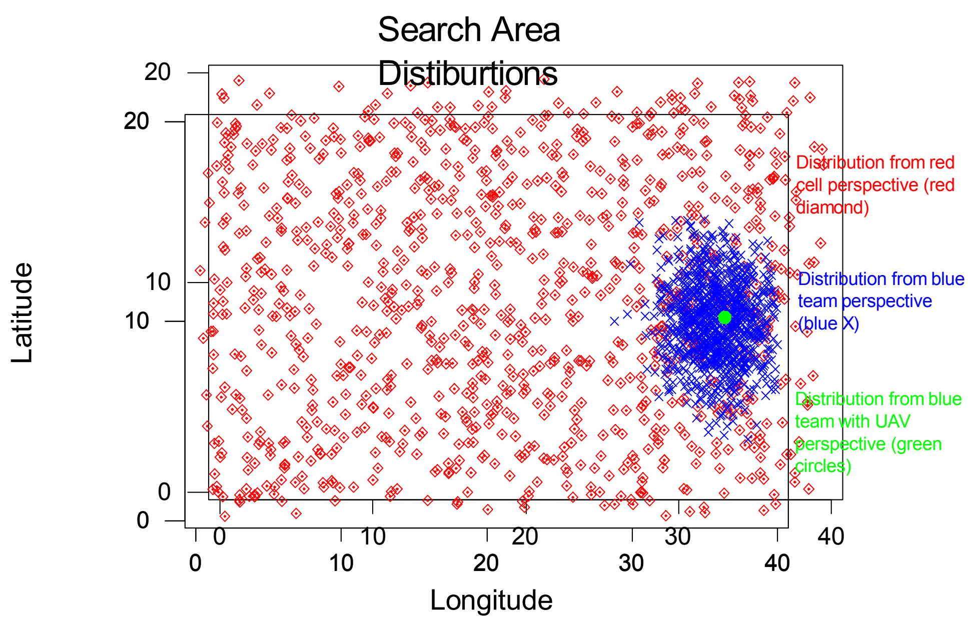

Figure 18. Force Distribution Locations

Verification:

Run simulations

Implementation:

Conduct LOE

Maintenance:

Analyze results, adjust experiment, and repeat or provide results to future researchers.

B. MEASURES OF EFFECTIVENESS (MOES)

The following measures of effectiveness were derived from and then validated by the mathematical model above.

Situational awareness

Command and Control

Target identification

Force protection

Cumulative distance between blue forces and pilot

Cumulative distance between red forces and all blue forces

Number of blue force detections of red forces

Number of red force detections of blue forces

Time to link up between pilot and blue force

Number of mission success (link up without compromise)

Command and Control (C2) red force location estimation

C2 blue force location estimation

C2 downed pilot location estimation

Qualitative responses to usability of UAV equipment in the field

C. DESCRIPTION OF SIMULATION

The models above also yielded the information needed to input into a simulation. Table 15, which displays the time each force needs to search, and Figure 18, which displays the randomly distributed possible force locations led the author to believe that the red force would most likely not encounter the blue force without providing the red force additional intelligence. This information was then entered into the simulation to verify results. The simulator utilized was the Multi-Agent Robotic Swarm Simulation (MARSS) developed by another international student at NPS, CPT Alistair Dickie (Australian Army). This simulation is an agent-based simulation developed to model the possible swarming characteristics of UAVs, and can be located on the World Wide Web at http://diana.gl.nps.navy.mil/~ajdickie/marss/. The following report was generated by CPT Dickie:

LT JOSH BUTNER LOE IMPLEMENTATION IN MARSS

Captain Alistair Dickie – Australian Army

During the period 16th to 20th September 2002, a limited objective live experiment to be conducted by LT Josh Butner later this year was investigated using MARSS. The live experiment consists of a Special Forces blue team searching for a blue downed pilot in an area with a hostile red team. The will be conducted with and without blue UAV support to determine the effectiveness of tactical UAVs in supporting Special Forces missions.

The aims of this analysis were to visualize the proposed experiment and gain some insight regarding the conduct of the experiment.

This scenario was partially implemented in MARSS.

Initially a base scenario was implemented that consisted of a blue entity representing the downed pilot, a single red entity searching for the pilot, and a single blue entity representing the special forces search team. Starting positions, search areas, sensor assumptions, and behaviors were implemented to as closely as possible replicate the proposed live experiment. The implementation of the extended scenario with blue UAV support was started, however not fully completed.

The measure of effectiveness of blue performance was simply the proportion of runs where they managed to locate and move to the downed pilot, prior to red detection of either the downed pilot or the blue Special Forces team. Qualitative results indicated that with the proposed experimental parameters the blue team would win almost all the time. From an experimental viewpoint this is somewhat concerning as it becomes difficult to show the effect of increased performance when the UAVs become involved.

Further discussion revealed that in reality Special Forces would rarely conduct similar missions if there were a high risk of contacting a red force. As the live experiment was being designed to reflect reality it was not surprising that the simulation suggested an overwhelming blue success.

This led to a slight change of philosophy regarding the aims of the overall experiment. By evening the odds in the base scenario, it is expected that the effect of the inclusion of UAVs could be shown much more effectively. This may show that tactical UAVs can do more than just support current missions; they may enable Special Forces to conduct missions that previously had been considered too risky.

While the live experiment was far from investigated fully using simulation, the analysis did provide limited insight [and needed changes in the experiment plan]. Further analysis could provide quantitative results on both the base and extended scenarios.

Figure 19 below contains a screen capture of the 3D view from MARSS. Shown is the VRML representation of the SWARM UAV that was used in the preparation of the extended scenarios. These scenarios were not completed.

Figure 19. MARRS Screen Capture One

The screen capture in figure 20 is the overall MARSS display. This shows the base scenario (no UAV support) running. The blue pilot is represented in the 3D display by a simple chess piece. Note the background used is an image of the map of the actual exercise area.

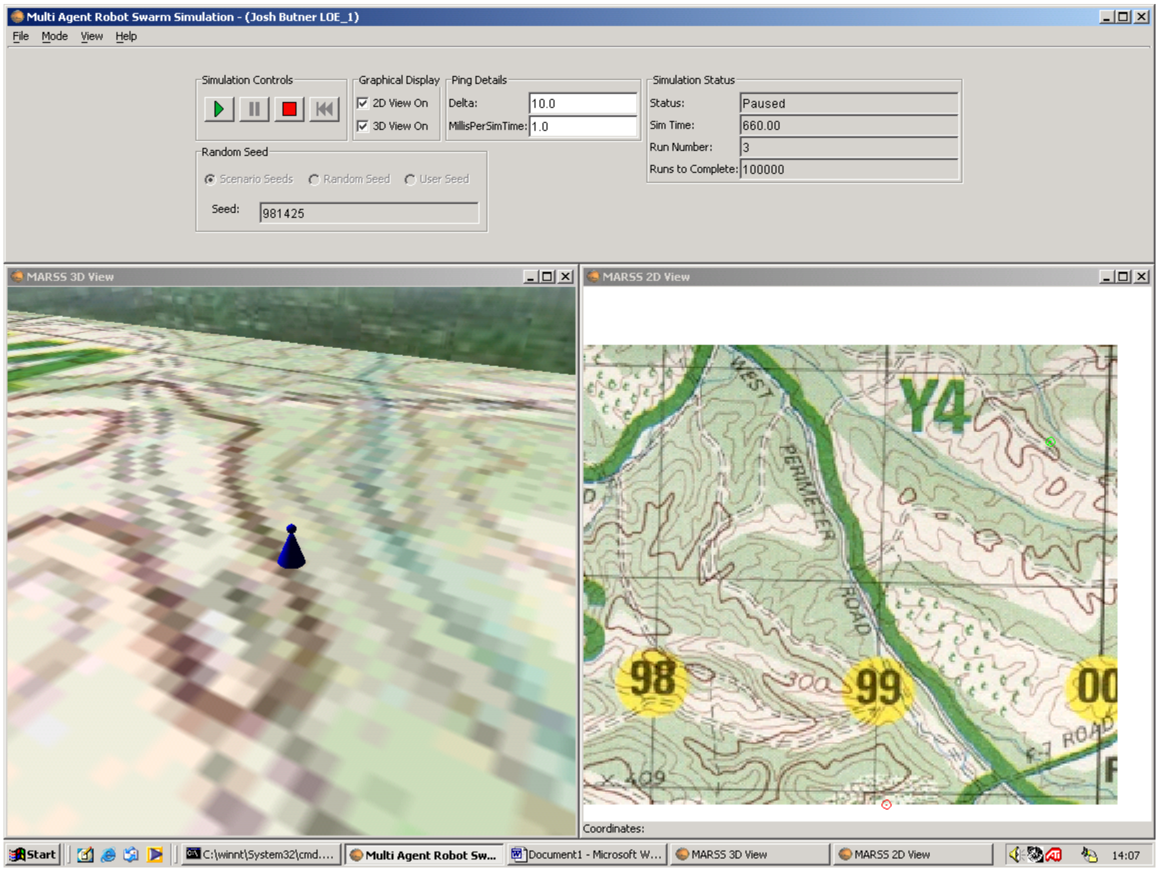

Figure 20. MARRS screen capture Two

End CPT Alistair Report.

CPT Alistair's MARSS simulation confirmed what had been identified in the mathematical model. The red forces needed to be given more intelligence to decrease the area they were required to cover. This was accomplished by reducing the red force search area from the entire two by four km op area to the two square kilometers in which the downed pilot was located.

VIII. CONCLUSION

A. PRESENT

The organizational network and the development of the limited objective experiment that tested emerging UAV technologies in an operational and analytical environment proved to be a workable concept that yielded rich results. The network consisted of national laboratories, business, interdisciplinary NPS working groups, students, operational forces, and operational commands (see participants). The loose network remains viable and stands ready to be tapped by future students.

Analysis of the actual integration of a tactical UAV with NSW forces during a NSW downed pilot recovery mission proved to yield useful data. This data inferred that a small, inexpensive, expendable, tactical UAV could impact NSW combat effectiveness in a positive way. The system tested may not be deployable today, but the idea proved sound and the parts that make up the whole of the system had a positive impact.

Finally, and most importantly, the research demonstrated that the use of an inexpensive, small UAV carrying, in this case, an IR camera and simulated communications relay capability, launched by rear echelon personnel, flown by onboard autonomous avionics to prescribed and changeable waypoints, emitting live video feeds to both the SEAL platoon in the field as well as the C2 element in the rear, proved to have a definite positive impact on the combat effectiveness of NSW forces.

While the experiment did not come to full fruition, much data was collected, and analysis of that data led to the following conclusions:

NSW forces don’t need, nor do they desire, to be burdened with the requirement of launching or flying the UAV. The concept of the TOC located at the Forward Operating Base (FOB), launching the UAV for the inserted NSW patrol, has been proven to be valid concept within an 8km range. This range will surely increase as video and communications improve.

Viewing a video feed in the field, during a foot patrol, near a target area may not be as advantageous as having a C2 element dedicated to viewing that feed, relay the information over a communications net capable of maintaining constant communications. (Note: the C2 element in the LOE was solely dedicated to observing and communicating with the single NSW element in the field).

The ability to track blue forces on the ground with a small tactical UAV has been demonstrated. The IR strobes utilized for the LOE purposes were not clandestine enough for operational use during special operations, but this limitation can be overcome.

NSW forces can quickly adapt to the use of these new technologies given these technologies don’t degrade current capabilities to provide new capabilities in different areas.

Developers of UAVs and their supporting technologies can benefit from feedback from operators in the field conducting LOEs.

The loose network developed enhanced both the design of the LOE as well as the dissemination of information. The dissemination of information included the results of this LOE being sent out and related information coming back in before the results were entirely collated.

B. FUTURE

The loose network developed remains active and a follow-on student has already shown interest in continuing some of this research as well as broadening the scope of the research. If anything, the network will grow as participants understand more fully the concepts and process of the LOE. The link to operational commands will continue to be the most difficult aspect of the network to maintain as their primary concern is correctly placed on mission accomplishment not research. However, some students may be able to gain “sponsorship” by operational commands if the research subject addresses that commands current needs.

The technology supporting small tactical UAVs is still developing. Optimal duration, speed, and payload capabilities do not currently exist in one aircraft. However, these capabilities are being rapidly developed and if money and interest were focused in a specific direction, perhaps designated as an NSW requirement, then this capability could be developed that much more rapidly.

Some examples of developing technologies that are directly related to the SWARM UAV are:

- An IBM Computer that interrogates a beacon through the camera onboard the UAV to positively ID personnel.

- New modems with a range of about 20 miles and a bandwidth of at least 1Mb/s. This will allow for extended range of autonomous flight as well as digital video transmission.
- Onboard computer filtration of images to determine if video is of interest and only transmitting that video in order to free up bandwidth for other aircraft.
- Generators for current SWARM engines that will erase the dependency on batteries.

All of these advancements in technology can increase the capability of these small tactical UAVs. Minimum operational requirements articulated by the users (NSW forces) based on data collected during this LOE and future LOEs could help focus these efforts and prioritize them.

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